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DIGITAL OPTICAL TRACKING SYSTEM

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DIRECTORATE OF TEST DATA
DEPUTY FOR TEST AND SUPPORT
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

PROJECT No. 6460, TASK No. 64601

NOTICES

FOREWORD

The Digitized Optical Tracking System (DOTS), a space-position measurement system, was derived through modification of an Orthogonal Coordinate Tracking System (OCTI) developed by authority of Project 6460, Task 64601, "Aircraft Position Measurement Equipment." Modification was necessitated by a Stratigic Air Command Dispersal Program construction which interfered with the original test range and because the mechanical portion of the system was proved unsatisfactory in an evaluation program.

The OCTI was a digitized, optical, space-position measurement system originally conceived in the latter part of 1951 by Mr. Charles Castle, then chief of the Measurement Unit of the Data Reduction Division.

Effective 21 April 1952, Air Force Contract No. AF-33(616)96 was negotiated with Land-Air, Incorporated, Instrument and Electronic Division, Oakland, California. This contract provided for study, design, fabrication, installation, and testing of a digital, optical space-position measurement system. Provisions of this contract were monitored by Mr. Norman Shanteau, Chief of the Test Facility Unit of the Directorate of Flight and All-Weather Testing, Mr. William O'Brien, and finally by Mr. Albert Smith, Engineers of the Facility Unit.

Work on this contract by Land-Air, Incorporated was terminated during February of 1957. Air Force personnel, under the supervision of Mr. Albert Smith, continued the work on this system. Construction was completed and an evaluation program performed during 1958. Results of the evaluation indicated the need for improvement or replacement of the optical instruments.

During 1959 work toward improvement of the OCTI System was continued mechanically by Mr. William O'Brien, and electronically by Mr. Albert Smith. For this work, three Askania cine-theodolites, Kth 53, instruments were obtained as replacements for the optical instruments in the existing OCTI system and digitized by mounting externally to the instrument shaft position encoders on the azimuth and elevation axes. By so doing, the original photographic dial capability of the instrument could be preserved and used as backup for the digital system if more accuracy were required.

Two encoders, the 13-bit Gurley Model 8613, and the 16-bit Dychro Model DV-16A, were obtained by Air Force contracts AF-33(616)59-659 and -702, and modification of the Kth 53 instruments to accomodate the encoders was started.

Reassignment of Mr. William O'Brien as a result of the 1960 reorganization made Mr. Albert Smith of the Systems Development Branch, Data Systems Division, Directorate of Test Data, responsible for the modification of the entire system.

During June 1960, checkout of the electronics was accomplished, modification of the first Askania Kth 53 instrument was completed, and an evaluation of the system performed. The evaluation revealed that the method of coupling the azimuth encoder to the azimuth axis of the instrument was introducing excessive error digitally. Restudy of this problem resulted in development of a coupling method superior to the original method, and in December 1960 two Askania Kth 53 cine-theodolites were completely modified, integrated into the system, and evaluated. The evaluation indicated accuracies well within the demands of the system.

Other personnel in the Data Systems Division who should be recognized for their contributions to the modification of the DOTS are Messrs. Linder C. Shoaff and Robert W. Bright for their work in modifying the Askania Kth 53 instruments and mounting of the encoders, and Messrs. Luster G. Hall and Ralph D. Lamme for their work in disassembly, reassembly, and realignment of the Askania instruments, and their assistance in modification of the system electronics.

Special credit should also be given to Mr. Robert Pollock of the Data Reduction Division, Directorate of Test Data, for his raw data smoothing techniques now under further refinement.

ABSTRACT

This space-position measurement system comprises two Askania Kth 53 cine-theodolite instruments with digital encoders mounted externally on their azimuth and elevation axes, readout electronic equipment including multitrack tape recording and playback subsystems, and a conversion subsystem for entering digital data in a Burroughs 205 computer.

Digitally, angular position readings are possible to ±1 part in 32768, and by a small modification, can be extended for azimuth angles to ±1 part in 65536. Sampling rates are 1, 2, 4, 8, or 16 per second.

Instrument dial angular position capability is five seconds of arc, for which film recordings are available for visual scanning.

Time, recorded in binary code, is accumulated each 2-second period in groups of eight frames each. Time correlation exists within the system, and is possible with external systems.

PUBLICATION REVIEW

This report has been reviewed and is approved for publication.

FOR THE COMMANDER:

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INTRODUCTION

Instrumentation systems of great accuracy are required to evaluate flight performance under test conditions. Test requirements frequently govern the test system employed, i.e., whether it be confined to the test vehicle itself, entirely ground assembled, or a combination of airborne and ground equipment. Coordination and compatibility of measuring systems have not been developed far enough to permit early availability of results. The major problem is the time involved in processing the raw data.

Raw data from measurements of aircraft in flight is acquired either entirely by optics, or electronics, or by combinations of both. When only optical data recording is employed, azimuth and elevation angles, time, instrument orientation, and operator tracking error, are obtained from the recording media by a reading process. Data so obtained is then punched into cards or tape, and eventually reaches the computer if computation is necessary.

In measurements involving long flight paths, or those employing several recording stations, the volume of recorded media is extensive. The time required to process this data from test to final results is considerable, and in many cases, a handicap to the project engineer. Electronic data recording significantly reduces this time element. It presents the data in an analog or some coded pulse form and then introduces it into a computer by translation equipment. For measurement within optical limits, the combination of optics and electronics makes possible rapid processing of raw data. Also the capability of correcting operator error is maintained, and greater accuracy in computation thus obtained.

The space-position measurement system described is a complete ground assembly combining the optic and electronic systems. Immediate translation of magnetic tape data into the computer yields almost instant interpretation of recorded data by the automatic data reduction equipment, thus eliminating manual processing of data and resultant delayed calculations.

GENERAL DESCRIPTION OF SYSTEM

The system's present geometry is composed of two stations. A study of various configurations of 2-station locations with respect to area of coverage, greatest possible accuracy, and types of flight test (present and anticipated) indicated an arrangement in which each station is situated on opposite sides of the test area runway, and in the approach and landing zone. Although, it is desirable to locate these stations on a line perpendicular to the runway centerline, it was not possible at this time, so the station locations were staggered on either side of the runway centerline. In figure 1, which indicates the system geometry, all indicated measurements originate from an arbitrarily selected point on the centerline of the runway and in the approach and landing zone. Survey of these station locations was to first-order-accuracy.

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The tracking instruments are elevated above the terrain for a clear view of the tracking area, and rest on steel reinforced concrete pedestals. Figure 2 shows the installation at Station No. 1. The pedestal is approximately 70 feet high, rests on an underground foundation, and is surrounded by a corrugated steel-plated cylindrical building which is isolated from the pedestal. Vibration of the pedestal is practically nonexistent. A canopy which can be folded down from the field of view when tracking, covers the instrument. A shelter room which also houses part of the electronic equipment, is near the top of the cylinder. The remainder of the electronic equipment for the station is located in the ground shelter.

Two target board locations were also included in the survey. One target board was allotted to each station for purposes of orientation of the tracking instrument and determining the magnification factor in scanning film recordings. Although a 3-target board per station geometry would perhaps be more desirable for leveling the cine-theodolite instrument (Askania Kth 53), area limitations dictated the use of one target board per station. Since the Askania instrument includes 5-second leveling bubbles, this was considered accurate enough for the demands of the system.

The optic equipment of the Askania Kth 53 cine-theodolite is combined with the electronic equipment through precision shaft angle encoders attached to the azimuth and elevation axes of the instrument. The associated electronic equipment comprises a central timing system to supply the necessary driving and synchronizing pulses, a reader system to interrogate the encoders, a tape recording system to store the digital angular information and various other pulse information, a playback system to recover this data from the recorded memory, a pulse standardizer to re-shape and time the recovered pulse information, a converter system to control the digital format for insertion of raw data into a computer, and finally, a Burroughs 205 computer with its associated output equipment. Figure 3 is a block diagram of the system.

DETAILED DESCRIPTIONS OF SUBSYSTEMS

Optical Instrument

The Askania Kth 53 cine-theodolite, figure 4, is utilized as the angle measuring device in this system. Its normal output of raw data is a photographic recording. Angle information, azimuth and elevation, is obtained from graduated dials that are mounted on the instrument axes. Its capability of angle measurement is five seconds of arc.

Digital output of angle measurement was achieved by coupling precision shaft angle encoders on the two axes. For azimuth-angle measurement, a Dychro Model DV-16A analog to digital converter was used. This encoder comprises a cyclic binary, 16-bit code disc, which is interrogated by a stroboscopic flash lamp which illuminates light-sensitive detector elements located on the opposite side of the disc. Voltage pulses, generated by the light detectors and determined by the transparent and opaque sector pattern of the code disc, are amplified and shaped in transistor amplifiers, one for each bit channel. The amplifiers are included in the encoder. Their output pulse is negative, essentially square, has an amplitude of 6 to 8 volts, and is approximately 50 microseconds wide. In physical size the encoder is 10 inches in diameter and 4 1/2 inches high. A coupling shaft of special length was required. It is 6.700±0.001 inches long, 0.5 inches in diameter, and has an ASA taper of 0.5986 inch/ft for approximately 1 1/4 inches at its outside extremity. The digital capability of this encoder is ±1 part in 65,536.

However, at the present time, only the first fifteen channels are being interrogated, and the capability is ±1 part in 32,768. Starting torque is approximately 3 inches/oz.

For measurement of the elevation angle, we used a 13-bit Gurley precision shaft position encoder, a manufacturer's stock item (model 8613) requiring no special features. This encoder also interrogates a cyclic binary code disc by the photoelectric principle, for which self-contained transistor amplifiers are provided for each channel. The output pulse for each of the amplifiers is negative, has an amplitude of 2 to 3 volts, and is approximately 50 microseconds wide at a 1-volt amplitude. The encoder is 6.930 inches long and 3.50 inches in diameter, and has a digital capability of ±1 part in 8192. The gearing used in mounting it on the Askania Kth 53 instrument extends its digital capability to ±1 part in 32,768. Starting torque is approximately 0.3 inch/oz.

To mount the Dychro encoder to the azimuth axis of the Askania instrument, a housing adapter was fabricated which slips over the shaft and is fastened to the top of the encoder by a bolt which passes first through a lock arm, and then the flange at the base of the housing. Figure 5 displays the adapter pictorially; figure 6 is a detailed drawing of it. The lock arm in the locked position (figure 7) prevents the encoder from rotating. As the encoder is installed (figure 8), the adapter housing passes through the center hole of the trivet and the various associated parts including the worm gear and azimuth circle assembly. The top cylindrical portion of the housing is a precision fit in the main bearing of the flange in this assembly. The nut, installed at the top of the housing and pressing against the retaining plate of the worm gear and azimuth circle assembly, locks the encoder to the trivet. Figure 9 shows the encoder as it rests against the bottom of the trivet, and figure 10 shows the lock nut in position.

To couple the encoder shaft to the main body assembly of the Askania instrument, the center cover disc was removed and the original hole increased in diameter to 2.1250 inches. A coupling collet lock was fabricated (figure 11) and placed down over the shaft and into the enlarged hole in the main body. A clearance of 1/16-inch between the lock and the hole wall was allowed for purposes of centering. When the Askania instrument was reassembled to this point, centering of the encoder shaft was accomplished by using a dial gauge, and then the coupling collet lock was anchored to the main body by the three bolts through the flange. Centering of the encoder shaft was accurate to 0.0005 of an inch. Figure 12 shows this installation. The lock nut clamps its fingers about the shaft and causes the encoder disc to rotate with the main body of the instrument. It also makes possible the setting of the encoder zero with respect to station location or instrument dial reading, as desired.

The Gurley encoder was coupled to the elevation axis of the Askania Kth 53 instrument by a fabricated large ring gear and a small pinion spring-loaded split gear (figure 13). The turning ratio is 4 to 1. To make room for the newly fabricated parts, it was necessary also to cut away part of the camera support casting of the main body of the instrument and part of the side cover of the protective covers. The ring gear replaced the gear wheel rim in the elevation optical train (figure 14). The "quick look" dial assembly was removed. The pinion split gear was attached to the shaft of the encoder (figure 15). The encoder was supported by an adapter plate, fabricated to replace the section of casting cut away from the camera support of the main body (figure 14). As the encoder is attached to this plate the pinion gear passes through the hole and meshes with the ring gear. Locks clamp the encoder to the adapter plate (figure 16). A new casting was fabricated (figure 17) to replace the portion of the protective cover that was removed. Complete final assembly of the elevation encoder is illustrated in figure 18.

The instrument was also equipped with a newly fabricated handle to aid slewing in azimuth. A silica (gel) compartment was devised as an aid to keeping the instrument's interior dry. Figure 4 shows the Askania Kth 53 instrument with all modification complete.

Instrument Electronics

General Description

Three racks house the electronic circuitry necessary for recording the cyclic binary pulse information from the encoders attached to the Askania Kth 53 instrument. The circuitry comprises wire line amplifiers, inverter amplifiers, timer, horizontal and vertical readers, matrix, multiplexer, line amplifier, camera control, strobic trigger, power supplies, control panel, and communication transmitters and receiver. Figure 19 shows the electronic rack detail, and figure 20 is a block diagram of the station electronic equipment. A brief description of each unit follows.

Wire Line Amplifiers

The control signals originating in the time standard equipment located at the master station are transmitted by 26-pair cables to the field station electronic equipment. The pulses are transmitted bi-polar, i.e., a pair of lines transmits two signals of opposite polarity spaced enough in time so that zero or a difference voltage will not occur. The wire line amplifiers terminate the cable pairs and serve to separate and shape the bipolar signals, thus providing a low impedance output. The amplifiers are composed of a differential amplifier, a monostable multivibrator and a cathode follower. Physical construction is of the plug-in type. Each rack assembly has a built-in power supply to furnish the necessary operating voltages, and a receptacle chassis with provision for the plug-in of five wire-line amplifiers.

The amplifiers receive the following driving signals from the central time system and, after separating and shaping, distribute them to the various units with which they are associated.

1. Shutter Pulse—4, 2, or 1 pulses per second. Used to trigger the camera control which generates the necessary pulse to operate the shutter mechanism.

2. Flash Pulse—Basic time pulse from which the other pulses are established relative to time.

3. Code Pulses—Binary code pulses which identify the associated block of eight film frames, and blocks of digital data.

4. Separator Pulse—Pulse identifying the first film frame in a group of eight frames. Identifies the start of each time code word.

5. Word-Rate Pulse—16, 8, 4, 2, or 1 pps. Used to trigger a scan pulse applied to the digital encoder reader section input gates and to cause storage of the cyclic binary count in the reader register.

6. Digit-Rate Pulse—1024 pps. Used to trigger the 5-stage divider which, through application of its output to a diode matrix, generates a chain of fifteen serial pulses that cause readout of the output gates following the reader section holding registers.

Inverter Amplifiers

Triggering of the input stage of each reader section requires positive polarity signals of 10 to 15 volts amplitude. Since the digital signals from the encoder transistor amplifiers are negative and vary from 2 volts for elevation to 8 volts for azimuth, inverter amplifiers are necessary. These are single-stage class A amplifiers. Variable output is available. There is an amplifier for each digital bit.

Timer

The function of the timing unit is to provide signals controlling insertion of data into the reader sections, and to generate readout of the data. The word-rate drive pulses from the wire-line amplifier are applied to a group of stages including shapers, differentiators, inverters, delays, gates, pulsed oscillator, and amplifiers. The output of the amplifiers is a series of eight pulses obtained from the pulsed oscillator operating at approximately 20 kc. A series of scan pulses is obtained for each word-rate pulse applied to the input.

The digit-rate pulses are first applied to a Schmidt shaper. The output pulses are then used to drive a 5-stage divider, whose outputs, in turn, are channeled through cathode follower stages to a diode matrix. Frequencies developed by this divider are: 512, 256, 128, 64, and 32 cps.

Matrix

The matrix circuit is a configuration of crystal diodes, which receive both positive and negative pulses of the above mentioned frequencies with exception of the 512 cps. In this case only the positive pulse is used. There are nine inputs to the selective circuit, and one output. Fifteen serial pulses are produced by the matrix for each complete count of the 5-stage divider and are used to release digital information from the output gates in the reader sections.

Azimuth and Elevation Readers

There are 15 azimuth and 13 elevation circuits, making a total of 28 sections. Circuitry of all sections is identical and comprises, mono-stable, bi-stable shaper, pentode input gate, bi-stable holding register, and a pentode output gate. The positive signal from the inverter amplifier is approximately 20 to 50 microseconds wide, and has an amplitude of 10 to 15 volts. This pulse is applied to the monostable whose RC period is approximately 400 microseconds. The negative pulses, developed by the monostable, control the bi-stable shaper which develops a positive square pulse of a 400-microsecond width at one plate. This pulse is applied to the suppressor grid of the pentode input gate and energizes this gate. The series of scan pulses developed by the word-rate pulse in the timer are applied to the control grid of the pentode input gate, and the output of this gate is thus a series of eight negative pulses. These are applied to the input of the holding registers. Although only one pulse is required to set this register, the remaining pulses give added assurance that this register will be set when a bit is supposed to be stored. The positive pulse of the holding register is applied to the suppressor grid of the pentode output gate and energizes this gate. The fifteen serial pulses from the matrix are then applied to the control grids of the pentode output gates, and, if a bit is stored in the holding register, a data pulse is readout. For the azimuth and elevation readers, readout is simultaneous. It is a cyclic binary representation; the pulses are negative with an amplitude approximating 120 volts and a width of one millisecond.

Multiplexer

The multiplexer is an electronic device which controls the width and timing of the output pulses from the reader sections to achieve time separation between the azimuth and elevation pulses. Azimuth bit information is channeled through an amplifier, clipper, delay mono-stable multivibrator, width mono-stable multivibrator, amplifier, and inverter. Elevation bit information is channeled through an amplifier, clipper, width monostable multivibrator, amplifier, and inverter. The elevation pulses are reduced in width from one millisecond to approximately 400 microseconds and the azimuth from one millisecond to approximately 400 microseconds. (Azimuth pulses are delayed 100 microseconds from the elevation pulses.) Outputs of each channel are negative with amplitudes of approximately 150 volts.

Line Amplifier

The line amplifier is composed of two amplifiers whose outputs are combined in the secondary winding of an output transformer, and appear as bi-polar signals on a single pair of lines. The azimuth and elevation output signals of the multiplexer are transmitted to the dual input stage of the line amplifier. This is a double diode clipping stage. Two amplifier stages follow each clipper stage. The plates of the second amplifier stages are connected to opposite ends of the center, taped, primary winding of the output transformer. Since the input signals have been separated in the multiplexer by slight differences in time, the swing of plate current in the primary winding of the output transformer induces voltage pulses of opposite polarity on the single pair of output lines. The separation between voltage pulses prevents differencing or zeroing of the voltage pulses. Thus, bi-polar transmission is achieved.

Camera Control

The camera control unit operates the shutter and flash mechanisms of the Askania Kth 53 instrument. This unit is driven by the shutter and flash pulses derived from the central time system.

The shutter pulse circuitry comprises an input clipper stage, delay monostable multivibrator, width monostable multivibrator, and a cathode follower containing the field coil of a sensitive relay. The shutter drive pulse passing through this circuitry controls the closing of the relay controls by contacts which switch 12 volts dc from an external power supply to the shutter mechanism of the Askania Kth 53.

The flash drive pulse from the central time system is used to turn on a thyratron switch. The trigger pulse generated by the switch, controls the flash circuitry of the Askania Kth 53.

The camera control unit has self-contained power supplies providing necessary bias voltages, positive operating voltages, and flash intensity voltage.

Encoder Stroboscopic Trigger

The encoder stroboscopic trigger is a thyratron switch driven by the word-rate pulse from the central time systems. It provides the necessary pulse to drive the pulser heads of both the azimuth and elevation encoders. The pulser head assembly comprises the capacitors and transformer required to fire the strobotron's light source.

Power Supplies

1. Sorensen regulator—To more completely stabilize operation of the circuitry in various units, regulation of the primary source was considered necessary. This Sorensen unit performs this function. Primary voltage regulation is ±0.1 percent.

2. Main power supply—A dual unit. Both sections are electronically regulated. Operating voltages for the reader sections, timer, and inverter amplifiers are obtained from these sources.

3. Pre-amplifier strobic power supply—A combination of four power sources. Two are low voltage and supply the necessary +18, +10, -12, and -3 volts required by the transistor amplifiers in the encoders. The remaining two furnish +300 and -300 volts required in the pulser head strobotron circuitry.

4. Camera motor supply—A low voltage, transistorized, commercial power supply, whose output range is 10 to 14 volts, at 15 amperes. It supplies the necessary 12 volts to operate the Askania camera shutters' mechanism.

5. Multiplexer power supply—Furnishes the necessary operating voltages for the multiplexer circuitry. The bias voltage is regulated by a voltage-regulator tube. Positive voltages are unregulated.

6. Line amplifier supply—An unregulated, conventional power supply. It provides operating voltages for the line amplifier.

Communications

Intercommunication sets (Land-Air, Incorporated's Model WP-30) maintain contact between operator personnel at the field stations or at the range control point. The sets are interconnected by a 26-pair land cable. Transmission of drive pulses and data pulses is also a function of this cable.

Figures 21 through 23 are views of the electronic racks at the DOTS no. 1 station. Since the Askania instrument at this station is at a considerable distance from the electronic racks, it was necessary to relocate some units identified with the racks, as in figure 19, in an auxiliary rack close by the instrument. This electronic rack is shown in figures 24 and 25.

Central Recorder

General Description

Digital position data from the two field stations is transmitted by the 26-pair land cable to the central recorder sub-system, which is located at the range control center. The necessary synchronizing and control pulses for entering this raw data in the computer conversion subsystem are obtained from the central time system, which is also located at the range control center. Nine channels of digital information comprising azimuth and elevation angle readings for each field station, flash, time code, separator, word rate, and digit sync (512 cps), are recorded. Excepting the word rate and digit sync, these signals arrive at the input of the record system as bi-polar. They vary in amplitude from 25 to 50 volts, and in widths from 400 microseconds to one millisecond. Figure 26 is a block diagram of the central recorder sub-system. Figure 27 is rack layout detail.

Differential Amplifiers

The input signals enter the record system through differential amplifiers. There are nine such amplifiers. They have diode clipping in their outputs, and serve to separate the bi-polar signals and to discriminate against noise. The pulses out of these amplifiers are 6 to 7 volts in amplitude and approximately 50 microseconds in width at 50-percent amplitude.

Record Amplifiers

Ten record amplifiers were used, all fabricated by Land-Air, Incorporated. Nine are actively employed in recording, and one is a spare. There are three stages of audio amplification employing resistive-capactive coupling. A fourth stage is used as a bias amplifier in nine of the amplifiers. In the tenth unit, the fourth stage is a bias oscillator and, by external coupling, it is common to the other nine units. No provision for erase has been incorporated in the amplifiers as no erase head is included in the record mechanism. Tape must be bulk-erased on an external tape degausser.

Multitrack Recorder

The recording mechanism, an Ampex Model 307-9, was equipped with a special Model 307 nine channel record and playback head assembly. It uses 1-inch wide magnetic tape and operates at speeds of 15, 30, and 60 ips. No erase head is provided.

Playback Amplifiers

Four playback amplifiers (also fabricated by Land-Air, Incorporated) are included in this subsystem. The amplifiers, a switching panel, and an oscilloscope provide a means of monitoring incoming pulses and those recorded on tape. There are seven resistance capacitive stages in the amplifier. The first stage is especially designed, mechanically and electrically, for low noise response. Cathode follower output is provided, and voltage output to 4 volts may be obtained. By means of a switch at the input, one of two different input lines may be channeled into each of these amplifiers. The fourth amplifier is provided with an input switch which will connect it with one of three input lines. Thus, the outputs of the nine playback heads may be switched into various playback amplifiers.

Switch Panel

The switch panel comprises four multicontact wafer-type switches interconnected in a manner such that a check can be made on pulses on any input line to the differential amplifiers, on the clipped output pulses from these amplifiers, or on the pulse outputs of the playback amplifiers.

Monitor Oscilloscope

The output of the master selector switch in the switch panel is coupled to an oscilloscope for monitoring. By observing the pulse outputs of the playback amplifiers, the operator monitors the pulses as they are recorded on the tape. A check of the entire system to this point is thus possible. The monitoring oscilloscope is a Tektronix, Type RM16, and is permanently mounted in the racks supporting this equipment.

Power Supplies

Three power sources supply the necessary operating voltages for the various amplifiers in this subsystem. These are standard units with dual choke-capacitor filters. No electronic regulation is used. A selenium rectifier with a resistance-capacitor filter provides dc for filament power.

Communications

Communication between personnel at the field stations and the operator of the central recorder is provided through the use of an intercommunication set (Land-Air's Model WP-30). Figure 28 is a photo of the central recorder subsystem.

Playback and Converter

General Description

The playback and converter subsystem is located close to the Burroughs 205 computer with which it is used. It consists of a playback mechanism, playback amplifiers, a pulse standardizer, and a conversion unit which performs a program that places the digital raw data into the computer. A single channel recorder-playback and its associated amplifiers and power supplies are also included. This is available for playback of any voice recordings made externally to the DOTS. Figure 29 shows a block diagram of this subsystem, and figure 30 gives details of the rack layout.

Multitrack Playback

Magnetic tapes previously recorded on the central recorder sub-system are played back on this unit. The mechanism is an Ampex Model 307-9, and is equipped with a special 9-channel playback head assembly. No record head assembly is included. It operates at 15, 30, and 60 ips speeds, and in fact, with the exception of recording heads, this mechanism is identical to that of the central recorder sub-system.

Playback Amplifiers

There are ten playback amplifiers, of which nine are actively utilized in playback and the tenth is a spare. Except for the fact that they have a single input, these amplifiers are identical to those in the central recorder subsystem.

Pulse Standardizer

The function of the pulse standardizer is to restore the sharp peaked digital raw data and control pulses to square pulses, to adjust their widths, and to space their occurrence in time. As in the field station electronic equipment, the angular position digital raw data is read from the holding registers in a serial format. Readout is accomplished by generating a serial trigger-pulse train with a 5-stage counter and crystal diode matrix. These pulses are used to trigger pentode gates which are set in an "ON" or "OFF" condition depending on whether the associated holding register does or does not contain a data bit. The serial readout occurs at the rate of 512 pps. A full count of the 5-stage counter generates 32 time slots. During the first two time slots, the scan pulses generated by the word-rate pulse transfers data bits to the holding register. At a word rate of 16 pps, this occurs 16 times per second. Of the remaining 30 time slots, there are 15 raw data and 15 digit sync periods, which alternate in occurrence. The 15 data bits comprise one data word. The generation time of the word is 31.25 milliseconds. At 16 pps a new word is started each 62.5 milliseconds. Thus, a period of 31.25 milliseconds exists between words. Figure 31 shows the data word configuration.

Due to the thyratron circuitry utilized in the digital data acquisition, the long transmission lines between the field stations and the central recording location, and the short transmission paths for the recorded control signals, time delays are inevitable. Pulse timing at the output of the pulse standardizer must match that shown in figure 31 for efficient functioning of the converter.

The pulse standardizer consists of nine identical channels, each of which has four stages of circuitry. The first stage is a clipping amplifier which discriminates against base line distortions and "over shoots." This is followed by a cathode-coupled monostable phantastron functioning as a delay control, and another such stage functioning as a width control. The output stage is a cathode follower. Pulses from the playback amplifier are passed through these stages and appear at the output as square pulses of the correct time relation.

Converter

The converter is a complex of electronic circuitry which accepts the binary time code bit information and the angular position cyclic-binary bit information; then, with the aid of the computer, it transfers this information to the computer memory for mathematical manipulation. It comprises shift registers, counters, amplifiers, gates, and blocking oscillators to perform this function. Its cycle of operation per space point is divided into an input and output phase. The input phase is controlled by the separator, word-rate and digit-sync pulses which were recorded on the magnetic tape along with the angular position information from the field stations. The output phase is controlled by the word-rate pulse of the Burroughs 205 computer. Figure 32 is a block diagram of the converter.

The output pulses of the pulse standardizer, namely, flash, time code, word rate, digit sync, and azimuth and elevation angular position of both field stations, are transmitted in parallel to the inputs of the converter. The input circuitry consists of five 15-bit shift registers. The first is for storage of time. The remaining four are for storage of the azimuth and elevation-angular position information of the two field stations. The separator pulse controls the gating of the time code to its shift register. Either an internal multivibrator pulse or the flash pulse can be gated into use for the purpose of shifting the register. The word-rate pulse controls the gating of the position bit data to their respective shift registers. The digit-sync pulses shift the registers. The amount of time required to enter the pulse information into the shift registers is 31.25 milliseconds. The last information bit entering the azimuth shift register of one station set, generates a pulse which advances a seven counter. The configuration of this counter controls gates which permit every second pulse of a three counter driven by the word-rate pulses of the Burroughs 205 computer to release a bit out of a shift register. The computer word-rate pulses occur at a 12-kc frequency or at one every 83.3 microseconds. Thus a bit is released from a register every 249 microseconds. Since there are 15 bits per shift register, release or shift-out requires 3.735 milliseconds. The first count of the three counter drives a sixteen counter. The configuration of the sixteen counter controls gates which permit each bit in the shift register, according to its placement, when shifted out, to trigger blocking oscillators which will set the proper toggles in the input register of the computer. The third count of the three counter initiates a computer add cycle. Thus, after the 15 bits have been shifted out of the shift register and 15 computer add cycles have been performed, a binary coded decimal sum is held in the accumulator of the computer. The sixteenth count of the sixteen counter triggers a two millisecond monostable multivibrator. During this period a pulse is transmitted to the computer which causes it to store in memory the accumulated sum. At the conclusion of the two millisecond period, readout of the next shift register begins. This operation requires a total time of 5.735 milliseconds for each shift register. Since there are five such registers, the total readout time per space position point is 28.675 milliseconds. The next input phase begins 2.575 milliseconds later.

A second sixteen counter is included in the circuitry. This counter is driven by the word-rate pulses (16, 8, 4, 2, or 1 pps) derived from the central time system, and recorded on the magnetic tape of the central recorder subsystem. Manual switch selection of output pulses from this counter controls gates which determine the number of samples per time period that will be transferred to the computer. If samples are recorded at sixteen per second (maximum for the system) it is possible to transfer 16, 8, 4, 2, or 1 samples to the computer by controlling gates by the switch configuration of this counter.

The converter was fabricated by the J. B. Rea Company, Inc.

Power Supplies

The power supplies for the playback and pulse standardizer are identical to those used in the central recorder subsystem.

The power supplies for the counter are built into the unit, and are electronically regulated.

Single-Track Playback

The single-track playback is an Ampex, Model 350R. The assembly includes the Model 350R record/playback amplifier and separate power supply. Quarter-inch magnetic tape is used.

Figure 33 shows a front view of this subsystem. The front panel of the pulse standardizer has been removed for maintenance purposes.

SYSTEM EVALUATION

Modification and mounting of the encoders on the first Askania Kth 53 cine-theodolite was completed during July 1960. In this particular instrument the manner of coupling the Azimuth encoder was different from that indicated in, "Optical Instrument," of this report. Shaft centering was possible only to 0.002 inch. Initial tests indicated excessive error between the Azimuth dial and digital angular readings. Also nonrepeatability existed. We determined that these errors were caused by the type of coupling employed, thus the Azimuth coupling method outlined in this report was devised and incorporated in the modification of the second instrument. It was completed in the early part of November 1960 and shaft centering to 0.0005 inch was obtained. Initial tests indicated good tracking between the azimuth dial and digital encoder, and stability was excellent. The first instrument, therefore, was remodified to include this type of coupling. By the early part of December 1960 modification of two Askania Kth 53 instruments was completed; they were installed at the field stations, and evaluation of the system was initiated.

Determination of Error, Instrument Dial Versus Digital Encoder

The first area of concern was determination of the magnitude of error between the instrument dial and the digital encoder angular readings. The azimuth encoder, as used, has an angle measuring capability of 2^{15} or 39.55 seconds of arc. The elevation encoder has an angle measuring capability of 2^{13} or 2.63 minutes of arc. However, the 4 to 1 gearing used to couple this encoder to its respective axis gives it the same angle-measuring capability as the azimuth encoder. Dial-measuring capability of the instrument is approximately five seconds of arc. For a given dial angle measurement, not considering external sources of error, the encoder angle measurement should be no greater than plus or minus one bit, or ±0.0109 degrees. External sources such as shaft centering, gear misalignment, gear imperfections, and human factors in scale interpretations can increase this error considerably. Two separate tests were performed to determine the magnitude of this error in both azimuth and elevation.

In the first test the instrument was rotated in azimuth by 20-degree spans, beginning at zero degrees, and the corresponding digital configuration recorded. Extreme care was exercised in setting the instrument dial angle. The cyclic binary bits in the digital configuration were converted to degrees. Differences between the dial and digital angles were obtained and compared to determine the magnitude of error. Measurements over 360 degrees of azimuth and 90 degrees of elevation were taken. Table 1 indicates the results obtained for one instrument.

Examination of these differences reveals that in azimuth the dial and digital angle readings, for the most part, are within the ±1 part in 32,768. At those settings where these limits are exceeded, the excess is only one or two thousandths of a degree.

In elevation the differences are much greater. A considerable bulge, negatively, indicates that the dial was turning at an increasingly greater angle than the encoder. Maximum deviation of five times the digital encoder capability is indicated.

To more clearly define the facts indicated in table 1 a second test was performed. The first test rotation procedure was advance, stop and read, then advance. This test motion, once started, continued uniformly throughout the 360 degrees of azimuth and 90 degrees of elevation. Sampling of the dial was by film, and of the encoder was by magnetic recording. Rate of rotation was adjusted so that approximately four samples per ten degrees was obtained. Angular data was obtained from the film record by visual scanning, and from the magnetic recording by the playback, converter, and Burroughs 205 computer. Differences between dial and digital angles were obtained and plotted. Figure 34 shows the plots for the same instrument as used in the first test.

The facts gleaned from the first test are again evident. In azimuth, from zero to approximately 100 degrees, there is a gradual buildup in the digital angle as compared to the dial angle. Then, quite abruptly, a reverse comparison holds. However, from 100 through 360 degrees, all samples fall within the limits of the encoder capability. The situation existing over the first 100 degrees apparently is caused by some mechanical fault, perhaps, a shaft stress, coupling play, or bearing problem. For the present, time has not been taken to resolve this problem, nor has it been considered serious since the physical layout of the DOTS hardly involves this encoder disc area while tracking a target. The plot of the azimuth encoder of the second instrument is within the ±1 part per 32,768 for the entire 360 degrees.

The elevation plot again shows the bulge in digital and dial angle differences, and reaching a maximum between 30 and 35 degrees. In this case the maximum deviation is further emphasized. The elevation plot of the second instrument does not indicate such a bulge, but the scatter of samples reaches a maximum of 0.030 degrees. Approximately one third of the samples lie within the capability of the encoders. Also, certainly, these differences can be identified with coupling problems, such as, gear construction, centering, alignment, and pressures. However, since the plots are repeatable, for the present, it has been considered adequate for the system requirements to program the computer to correct for the digital angle error.

Fixed Ground Target Measurement

Having determined the dial and digital angle reading capabilities of the instruments, the second area of concern was determining the accuracy of the system in measuring the position coordinates of known targets. Instrument dial and digital angles would be recorded, and position solutions for each performed. Results, in each case were to be compared with the known coordinates to determine the degree of accuracy.

To accomplish this test a series of points were accurately established in the approach area of the main runway, by using a Wild T-2 theodolite and good surveying practices. A total of seven points were located. Six of these were situated along the centerline of the runway, and one was offset. Figure 35 shows the layout of these points. At each point a target light was erected and its elevation determined. The instruments at both field stations were operated in the direction of tracking until they were aligned on the particular target and the azimuth and elevation dial and digital angle readings were then recorded. Single- and dual-station solutions were obtained for the counterline targets. A dual-station solution was used for the offset target. Table 2 lists the known coordinates of the targets, the computed single-station centerline values, and the dual-station computed values. Values listed in the first horizontal line, per each point, were determined from dial angles only. Those in the second line were determined from digital angles only. Corrections for instrument orientation were included in the solutions. Instrument alignment on each target was by one trial only. X-distances (range) are from the runway reference point. Actual range from the more remote of the two field stations would be the indicated values increased by 3734.173 feet. As an example, point no. 7 actually is 10,937.173 feet in range from the more remote field station.

Table 3 shows the differences between the known and computed coordinates of each target location. In range (approximately 7300 to 11,000 feet) the average error, using dial angles, is 1.165 feet for DOTS's no. 1 single-station solution, 1.627 feet for DOTS's no. 2 single-station solution, and 1.231 feet for dual-station solution. The maximum range error on any one target is 1.761 feet for DOTS's no. 1, 3.606 feet for DOTS's no. 2, and 3.004 feet for dual-station, dial-angle solutions. The average error in elevation, using dial angles, is 0.887 feet for DOTS's no. 1 and 1.132 feet for DOTS's no. 2, single-station solutions, and 0.544 feet for dual-station solution. Maximum elevation error on any one trial is 1.819 feet for DOTS's no. 1, 2.180 feet for DOTS's no. 2, and 1.077 feet for dual-station solution.

Using digital angles in computation, the average range error is 2.926 feet for DOTS's no. 1 alone, 1.279 feet for DOTS's no. 2 alone, and 2.063 feet for dual-station solution. Maximum range error on any one target is 4.604 feet for DOTS's no. 1, 2.710 feet for DOTS's no. 2, and 4.579 feet for dual-station solution. In elevation the average error is 1.163 feet for DOTS's no. 1 and 0.820 feet for DOTS's no. 2, single-station solutions, and

0.930 feet for dual-station solutions. Maximum elevation error on any one target is 2.404 feet for DOTS's no. 1, 1.493 feet for DOTS's no. 2, and 1.223 for dual-station solution.

Comparing the dial and digital average errors in position measurement of these fixed targets, the dial measurement was approximately 1.6 times more accurate in range, 2.9 times in azimuth, and 1.14 times in elevation. Considering the fact that the dial must move approximately 0.0109° to effect a 1-bit change digitally when the equipment is functioning normally, all measured values are well within the plus-minus maximum error limits that could exist between the dial and encoder. Scattering of position points will occur, and it is possible that at some sample times during a tracking mission, the maximum error between the dial and digital measurements will be present.

Tracking Moving Targets

The third phase of the evaluation involved tracking of moving targets. In one test a truck was driven the length of the main runway. It traveled at a rate of approximately forty miles per hour, and followed the centerline of the runway. The DOTS instruments were aligned on a flashing light on top of the truck to measure its path. Two operators for each instrument were used during this test, and instrument alignment was controlled through the gearing of the hand wheels. Both digital and dial-angle measurements were recorded. The sampling rate was four samples per second, and the average distance traveled between samples was approximately 15 feet. Computation of points of position were performed in the following ways:

1. Dial angles—corrected for operator tracking errors.
2. Digital angles—unsmoothed final values.
3. Digital angles—smoothed final values.

The first manner of computation provided the greatest accuracy from the system, and the basis of comparison for the other methods. This, however, does not eliminate such errors as film reading and card punching. Unless considerable care is exercised in performing these functions, errors of fair magnitude may be introduced.

Comparison of the computed elevation values (Z-coordinates) obtained from the dial angles (including operator tracking error corrections) against the known contour of the runway, indicated an average error of 0.531 feet. The maximum elevation deviation of any one point was 1.50 feet. If the truck followed the centerline of the runway without deviation, the average error in azimuth (Y-coordinate) values was 0.432 feet. The maximum deviation in azimuth for any one point was seven feet.

A similar comparison with computed digital-angle values indicated the average error in elevation to be 1.1003 feet, smoothed, and 0.926 feet, unsmoothed. Maximum elevation deviation of any one point was 2.60 feet, smoothed, and 2.00 feet, unsmoothed. The average error in azimuth values were 1.569 feet, smoothed, and 2.113 feet, unsmoothed. The maximum deviation in azimuth for any one point was 13.0 feet, smoothed, and 22.0 feet, unsmoothed. As the average deviations show, these maximum deviations occurred only a few times in the approximately 730 recorded samples.

A further comparison between computed values using dial angles (operator tracking errors included) and digital angles (using both smoothed and unsmoothed results) was made to determine the average error, and the maximum single-point error for each of the three coordinate values. In range (X-coordinate) the average error was 1.951 feet, smoothed, and 2.247 feet, unsmoothed. Maximum deviation for any one point was 11.0 feet, smoothed, and 15 feet, unsmoothed. In azimuth (Y-coordinate) the average error was 1.894 feet, smoothed, and 2.250 feet, unsmoothed. Maximum deviation for any one point was 15.0 feet, smoothed, and 24 feet, unsmoothed. In elevation (Z-coordinate) the average error was 0.958 feet, smoothed, and 0.497 feet, unsmoothed. Maximum deviation for any one point was 2.0 feet, smoothed, and 2.0 feet, unsmoothed.

A total of 730 samples were recorded in this test. Twenty samples falling in the obviously discounted area between stations were excluded. Range and elevation computations remained fairly good in this region. However, azimuth computation deteriorated because of the very small angles. Also, in this region, operator tracking error was excessive because of the high rate of movement of the target, and resultant high turn rate of the instrument. Testing in this area should therefore be limited.

Further tracking tests of moving targets involved tracking of approximately 35 aircraft missions, to include takeoffs, approaches, fly-bys, and landing of various types of aircraft. Several fly-by trackings were made simultaneously with the grid camera tracking system, for comparison of measured position values, in a common area of tracking between the two systems.

During most of the tests, a single operator was used at each field station. Operation of the instrument in azimuth was accomplished by disconnecting the gearing of the hand wheel and slewing. Elevation motion was controlled through the gearing of the hand wheel. Two operators per instrument would have been more desirable. However, during most of this period, they were not available.

Film recordings were made of all trackings. Visual reading of these afforded a comparison of dial and digital angle measurements, an estimate of the magnitude of operator tracking error, instrument leveling and orientation errors, and, finally, a feeling for accuracies of noncorrected versus corrected data.

Tracking range, for the most part, is dependent on visibility and altitude of the target. Aircraft identifications such as vapor or smoke trails, landing lights on, and position location through radio communication are also helpful. Other aids in tracking were provided by the Askania instruments, which are equipped with the sighting telescope combination of $5 \times 13^\circ$ and $20 \times 3^\circ$ capabilities. During this period of evaluation, the most extended range of tracking was approximately 20 miles. By employing techniques as suggested above, this range could be extended. However, accuracy of the system depreciates as the range increases.

Table 4 shows a small portion of the coordinate values for range, azimuth, and elevation as computed from the digital angles measured by the field stations during one aircraft fly-by tracking. Sampling rate during this run was 16 samples per second. Time readout occurred each 2-second period. Computation included instrument leveling and orientation. However, it did not include operator tracking errors or any smoothing techniques. Elevation values were quite smooth because the aircraft endeavored to fly a fairly constant altitude. Differences between successive samples in range and azimuth exhibited more unevenness. The increase in roughness, sample to sample, was directly proportional to the rate of the target movement; it was inversely proportional to the distance between the instrument and the target. Examination of the entire tracking record revealed a cyclic pattern of roughness, and this was attributed to the irregular movement of the instrument resulting from position changes by the operator as the instrument rotated.

The greatest contributing source of roughness in data was the tracking inadequacy of the single instrument operator. In most missions elevation changes should be gradual, and thus computed values should exhibit considerable smoothness. During the missions in this evaluation, the elevation angles were generated as a result of the gearing and manual operation of the hand wheel of the instrument, and azimuth was accomplished by slewing. Although, for the most part, angles in this plane were quite smooth, as verified by visual reading of the film recordings and measurement of off-center tracking, as the distance between the tracking stations and the target decreased and the rate of approach increased, the alignment errors in range and azimuth became greater, and at cross range these errors reached a maximum. Normally, the instrument operator endeavors to align on a specific point on the aircraft, such as the nose, wheel, light, or a point on the fuselage. Generally, the test engineer specifies the point to be tracked. At extended range the entire aircraft appears as a small object, and even though its rate of motion seems low, positive identification of a particular point is impossible at best, and operator error could extend over the entire aircraft. Smooth tracking by slewing is particularly difficult. The gearing of the instrument is disengaged and rotation is accomplished by pulling or pushing a handle attached to the main body of the instrument.

To identify the magnitude of tracking error occurring under these conditions, the film records were scanned and the tracking errors determined. Approximately 60 percent of the samples were judged to be on target. The average error in azimuth angles was 0.0625 degrees, and in elevation angles, 0.0188 degrees.

To further clarify the operator tracking problem, during several trackings two operators were used at one of the two field stations. The gearing and hand wheel facilities of the instrument in both azimuth and elevation were utilized. At the second station a single operator tracked in elevation by using the instrument hand wheel and gearing, and in azimuth by slewing. A comparison of the smoothness of tracking revealed that the use of two operators produced an improvement of approximately 50 percent.

A check of the operator tracking errors in azimuth and elevation angles was made for the truck test. Here the rate of motion was slow compared to that of aircraft. Two operators were employed at each station, and the hand wheels and gearing of the instrument were utilized for tracking in both planes. The average errors in azimuth and elevation angles were 0.0215 and 0.00372 degrees, respectively.

These results for the same target tracking are also shown in table 4. The values in (b) were computed using dial-angle measurements, uncorrected for operator tracking error. Those in (a) were computed using digital-angle measurements. Digital samples were taken at 16 per second, dial samples at four per second. The bracketed portion in the dial coordinates corresponds to the digital portion displayed. This portion of the tracking is illustrated because it shows particular roughness in range and azimuth values between range values 3366- and 3913-. This area of coverage lies between the perpendicular from the instrument to the centerline of the runway, and divides about equally across a line drawn between the two stations. As mentioned previously, this is the most difficult area for tracking, and should, if possible, be avoided.

Several missions were tracked simultaneously with the grid camera measurement system. This system photographs the target through a calibrated wire screen as the target moves in range along the centerline of the runway. Its accuracy of measurement depends on how closely the target follows the centerline. It has no provision for determining deviation from this centerline. Unfortunately, the test aircraft was unable to follow the runway centerline. From visual scanning of the film record and interpolation of target position between the screen wires, range and elevation were determined. Our interest in this phase of the evaluation was in comparing the elevation values recorded by both systems. The DOTS recorded off-center azimuth values of some 300 to 600 feet for various runs. Recorded elevation values for the two systems indicated differences up to 20 feet. By mathematically offsetting the runway centerline of the grid camera system to those values measured by the DOTS and by calculating the corresponding elevation values, agreement within 2 to 4 feet was obtained for the two systems. Had more exact physical dimensions for the grid camera system been known, less difference in values could possibly have been achieved. The big advantage of the DOTS over the grid system is that it records these off-centerline values and gives elevations corresponding to them.

CONCLUSIONS

The original interest was to provide a space-position measurement system which would shorten considerably the time necessary to reduce data for a test, and in so doing, provide reasonable accuracy. The digital recording technique has provided reasonably short data reduction time. Availability of the computer with which the system is used, largely governs the elapsed time between conclusion of a test and receipt of the reduced data. For some tests, during our evaluation, this amounted to one day.

Roughness of reduced data can be smoothed in several ways. Foremost of these would be the smoothing of raw data. This requires more careful alignment on the tracking point on the target by the instrument operators. Dual operators for each instrument, making use of the hand wheel and gearing facilities for rotation, and having a keen desire to do an especially good job, would improve the raw data. Presently, the training of additional operators is being accomplished.

Secondly, since the dial-angle measuring capability is finer than the digital encoder, these measurements can be used in tests requiring greater accuracy by reading the film recordings of azimuth and elevation angles. If care is exercised, these can be accurate to possibly 0.002 or 0.003 degree. Pictures of the target are generally good, and the data dials very good. Figure 36, showing the aircraft and dial detail, was reproduced from the film recording of one evaluation tracking. The great disadvantage in measuring the operator-tracking error is the time consumed in film reading angle-corrections and punching raw data into cards. If only a few points are of concern, time and effort are small. However, in long trackings and with large volumes of raw data, time involved using the dial-angle measurement system would extend into weeks.

A third possible method of smoothing involves mathematical techniques now being perfected (table 4 (c)) in which reduced data values smoothed mathematically, (a) digital versus (b) dial, with no correction for operator error, appear to approach those obtained by film scanning, as pointed out in the preceding paragraph.

Finally, roughness in data can be controlled to a degree, by performing the flight test in a portion of the coverage area favorable to the parameters being measured. Based on instrument error only, azimuth is good at a distance from the field stations, but becomes poor close in. Range and elevation reading accuracy degrade with distance. Figure 37 illustrates quadrilaterals of error based on a plus-minus constant-angle error applied to both stations.

Present knowledge of the DOTS would indicate, that for digital output, at elevations from 0 to 1000 feet, and within the immediate vicinity of the main runway, measurements of aircraft position can be achieved to an accuracy of 3 to 5 feet. This excludes the range and azimuth values in the vicinity of the line of stations. At 2- and 5-mile distances, accuracies of 15 to 20 and 70 to 75 feet are possible. Beyond five miles, accuracies deteriorate more rapidly, amounting to some 300 or 400 feet at 10 miles. By using the dial angle output of the instruments without operator tracking corrections, a slight improvement in accuracy over digital values may be achieved. To obtain the greatest accuracy from the system, operator tracking errors must be included in the mathematics. This requires visual film reading. The film reader must measure the position of the tracking point with respect to the fiducial lines of the film frame. These distances are translated to angle values and serve as corrections to the angle measurements recorded by the dials. Accuracies to three times the digital accuracies are possible.

RECOMMENDATIONS

Should future use of the system warrant refinements, the following items are suggested.

1. The azimuth encoder has a capacity of 16 bits. This is a resolution of 19.775+ seconds of arc. Presently, 15 bits are being used, and resolution is 39.55+ seconds of arc. With the present circuitry and timing, it would be a major task to make the necessary changes to accomodate an extra bit. We believe it possible to circumvent this equipment and cause the computer to accommodate the 16th bit. Programming the computer would then include the value of the 16th bit after angle measurements have progressed beyond the 15th bit. Also, if providing the digital output could be introduced to a translator which would provide the necessary computer format.

2. The importance of smooth tracking by the instrument operators has been indicated. Variable speed, reversible motors attached to the instrument azimuth and elevation gear chassis would permit smoother turning. Provision for disengaging the motors should be incorporated. In this way the instrument could be rapidly aligned on the target, and then the motors engaged for tracking.

This could be supplemented by a mobile platform or an adjustable operator seat, which would move with the instrument. The tracking roughness due to physical adjustments of the operator to the rotating instrument would thus be eliminated.

3. An electronic device for detecting and digitizing operator tracking error, and correcting the digital-angle readout by this amount would increase the accuracy of the digital measurements.

4. Finally, the present dome covers for the instrument shelters are of canvas construction. In time replacement will be necessary. A more satisfactory dome would be one constructed of plastic or metal with a sliding panel which would permit an open slot for the telescopes to view the target. The slot could be closed by sliding the panel and the shelters thus made weatherproof. The dome should be motorized to move with the instrment.

TABLE I

DIFFERENCES, DIGITAL ANGLE VERSUS DIAL ANGLE

AZIMUTH			ELEVATION		
DIAL (DEGREES)	DIGITAL (DEGREES)	DIFFERENCE (DEGREES)	DIAL (DEGREES)	DIGITAL (DEGREES)	DIFFERENCE (DEGREES)
0	0.000	+0.000	0	0.967	+0.000
20	20.006	+0.006	10	10.953	-0.014
40	40.012	+0.012	20	20.929	-0.038
60	60.007	+0 007	30	30.916	-0.051
80	80.013	+0.013	40	40.935	-0.032
100	99.998	-0.002	50	50.955	-0.012
120	119.993	-0.007	60	60.978	+0.007
140	139.988	-0.012	70	70.972	+0.005
160	159.994	-0.006	80	80.991	+0.024
180	179.989	-0.011	90	90.978	+0.011
200	199.995	-0.005			
220	220.001	+0.001			
240	240.007	+0.007			
260	260.002	+0.002			
280	279.998	-0.002			
300	300.004	+0.004			
320	319.999	-0.001			
340	340.005	+0.005			
360	359.989	-0.011			

NOTE:
Comparison: Digital dial (+)

TABLE 2

COORDINATES OF FIXED TARGETS

POINT No.	KNOWN COORDINATES			DOTS No. I CENTERLINE COORDINATES			DOTS No. 2 CENTERLINE COORDINATES			DUAL-STATION COORDINATES		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	+3580.700	±0.0	+12.500	+3582.461	±0.0	+11.294	+3579.102	±0.0	+11.537	+3580.265	+0.532	+11.423
				+3578.006	±0.0	+10.784	+3583.410	±0.0	+11.783	+3580.338	-1.229	+11.277
2	+3685.600	±0.0	+14.500	+3685.722	±0.0	+12.681	+3685.395	±0.0	+16.680	+3685.164	-0.086	+14.734
				+3686.101	±0.0	+12.949	+3686.025	±0.0	+15.489	+3685.885	-0.050	+14.395
3	+4033.900	±0.0	+15.200	+4032.447	±0.0	+15.214	+4032.455	±0.0	+14.532	+4032.166	-0.181	+14.875
				+4029.737	±0.0	+15.660	+4033.488	±0.0	+16.693	+4031.543	-1.017	+16.171
4	+4023.900	-220.9	+15.800	(LOCATION OFF CENTERLINE)						+4022.599	-220.060	+16.345
										+4023.375	-219.895	+16.838
5	+4251.800	±0.0	+15.200	+4252.693	±0.0	+15.349	+4249.458	±0.0	+16.067	+4250.338	+0.444	+15.715
				+4248.418	±0.0	+14.897	+4250.180	±0.0	+16.347	+4248.981	-0.465	+16.153
6	+5143.500	±0.0	+15.500	+5144.588	±0.0	+16.370	+5142.955	±0.0	+13.528	+5143.254	+0.097	+14.953
				+5145.713	±0.0	+16.043	+5144.720	±0.0	+15.221	+5147.016	+0.844	+16.626
7	+7203.5	±0.0	+110.50	+7201.827	±0.0	+109.238	+7199.874	±0.0	+110.644	+7200.496	+0.048	+109.939
				+7192.896	±0.0	+108.196	+7204.786	±0.0	+110.304	+7198.921	-1.778	+111.599

Notes: (1) The first horizontal line per point is computed from dial angles.

(2) The second horizontal line per point is computed from digital angles.

(3) Values in feet.

TABLE 3

DIFFERENCES BETWEEN KNOWN AND COMPUTED COORDINATES FOR TARGET LOCAT'ONS

POINT No.	DOTS No.1 CENTERLINE COORDINATE ERROR			DOTS No.2 CENTERLINE COORDINATE ERROR			DUAL-STATION COORDINATE ERROR		
	X	Y	Z	X	Y	Z	X	Y	Z
1	+1.761	±0.0	-1.206	-1.598	±0.0	-0.963	-0.435	+0.532	-1.077
	-2.694	±0.0	-1.716	+2.710	±0.0	-0.717	-0.362	-1.229	-1.223
2	+0.122	±0.0	-1.819	-0.205	±0.0	+2.180	-0.436	-0.086	+0.234
	+0.501	±0.0	-1.551	+0.425	±0.0	+0.989	+0.285	-0.050	-0.101
3	-1.453	±0.0	+0.014	-1.445	±0.0	-0.668	-1.734	-0.181	-0.325
	-4.163	±0.0	+0.460	-0.412	±0.0	+1.493	-2.357	-1.017	+0.971
4	(LOCATION OFF CENTERLINE)						-1.301	-0.840	+0.545
							-0.525	-1.005	+1.038
5	+0.893	±0.0	+0.149	-2.342	±0.0	+0.867	-1.462	+0.444	+0.515
	-3.382	±0.0	-0.303	-1.620	±0.0	+1.147	-2.819	-0.465	+0.953
6	+1.088	±0.0	+0.870	-0.545	±0.0	-1.972	-0.246	+0.097	-0.547
	+2.213	±0.0	+0.543	+1.220	±0.0	-0.279	-3.516	+0.844	+1.126
7	-1.673	±0.0	-1.262	-3.626	±0.0	+0.144	-3.004	+0.049	-0.561
	-4.604	±0.0	-2.404	+1.286	±0.0	-0.296	-4.579	-1.778	+1.099

NOTES: (1) Minus sign indicates less than known coordinates.
(2) Plus sign indicates greater than known coordinates.
(3) Values in feet.

TABLE 4

COMPUTED COORDINATES OF AIRCRAFT TRACKING

TIME	RANGE	AZIMUTH	ELEVATION	RANGE	AZIMUTH	ELEVATION	TIME	RANGE	AZIMUTH	ELEVATION
60	2646-	351	177	780	308	178	60	2640-	338	176
	2658-	349	177	577	289	181		2654-	338	176
	2667-	337	177	333	294	178		2666-	334	176
	2677-	327	177	33	319	175		2679-	332	176
	2690-	323	176	199-	316	174		2695-	331	176
	2707-	324	176	444-	317	173		2710-	331	176
	2726-	329	176	682-	311	.73		2727-	328	176
	2743-	331	176	946-	342	174		2740-	321	176
	2756-	321	177	1158-	297	175		2754-	312	176
	2767-	306	177	1423-	312	177		2765-	305	176
	2779-	295	177	1664-	301	178		2783-	302	176
	2795-	295	177	1914-	311	175		2800-	306	176
	2815-	306	177	2158-	320	181		2817-	309	176
	2836-	319	177	2396-	322	179		2833-	315	176
	2853-	327	177	2646-	352	177		2848-	317	176
	2865-	323	177	2691-	323	177		2862-	317	176
	2875-	317	177	2756-	321	177		2875-	320	176
	2888-	317	177	2815-	307	177		2891-	326	176
	2905-	324	177	2876-	318	177		2909-	332	176
	2924-	336	177	2943-	344	177		2927-	336	176
	2942-	343	177	2993-	304	178		2941-	336	176
	2958-	339	177	3052-	348	181		2956-	330	176
	2971-	327	178	3107-	275	180		2968-	325	176
	2982-	314	178	3169-	232	180		2981-	315	176
	2993-	304	178	3222-	217	181		2993-	308	178
	3005-	305	179	3300-	338	180		3006-	307	178
	3019-	313	179	3367-	343	181		3020-	313	179
	3035-	330	180	3462-	676	180		3036-	318	179
	3052-	347	180	3832-	3434	180		3050-	326	180
	3067-	347	181	3520-	106	180		3065-	325	181
	3080-	330	180	3614-	501	180		3079-	312	181
	3092-	298	180	3681-	509	180		3093-	295	181
70	3107-	274	180	3732-	430	180	70	3108-	279	181
	3122-	256	180	3790-	355	180		3124-	263	181
	3137-	244	180	3857-	432	180		3138-	250	181
	3153-	238	180	3913-	400	182		3152-	235	181
	3168-	229	180	3978-	344	181		3166-	219	181
	3181-	214	180	4027-	333	182		3180-	211	181
	3193-	200	180	4091-	334	182		3192-	202	181
	3206-	197	180	4154-	366	183		3208-	205	181
	3221-	214	180	4216-	343	183		3225-	219	181
	3240-	245	180	4270-	353	183		3243-	244	181
	3260-	282	180	4327-	358	184		3261-	270	181
	3281-	320	180	4373-	418	183		3279-	304	181
	3300-	337	180	4450-	337	184		3294-	313	181
	3313-	322	180	4508-	318	184		3309-	313	181
	3325-	292	180	4572-	330	185		3326-	327	181
	3342-	293	180	4637-	350	186		3347-	352	181
	3366-	337	180	4695-	365	185		3372-	386	181
	3394-	432	180					3396-	441	181
	3423-	544	180					3418-	498	181
	3446-	636	180					3439-	544	181
	3460-	662	180					3466-	646	181
	3472-	670	180					3480-	747	181
	3483-	667	180					3488-	752	181
	3515-	816	180					3488-	678	181
	3769-	2892	180					3481-	539	181
	3429-	213-	180					3471-	533	181
	3470-	23-	180					3486-	191	181
	3497-	62	180					3500-	158	181
	3519-	108	180					3518-	161	181
	3543-	189	180					3540-	199	181
	3566-	271	180					3566-	285	181
	3590-	377	180					3589-	375	181
80	3614-	503	180				80	3612-	453	181
	3637-	606	180					3634-	514	182
	3659-	614	180					3652-	541	181
	3667-	569	180					3668-	531	181
	3681-	509	180					3683-	515	181
	3694-	469	180					3694-	490	181
	3708-	445	180					3707-	469	181
	3720-	440	180					3719-	451	181
	3732-	434	180					3732-	427	181
	3745-	418	180					3745-	403	181
	3759-	391	180					3760-	383	181
	3774-	364	180					3775-	377	181
	3790-	357	180					3791-	383	181
	3808-	380	180					3808-	396	181
	3825-	417	180					3825-	411	181
	3842-	434	180					3840-	417	181
	3857-	432	180					3856-	416	181
	3871-	420	180					3871-	414	181
	3884-	404	180					3885-	412	181
	3898-	396	180					3900-	409	181
	3913-	402	181					3915-	404	182
	3929-	404	181					3931-	396	182
	3944-	389	181					3947-	381	182
	3963-	368	181					3962-	363	182
	3978-	345	181					3977-	350	182
	3991-	333	181					3989-	339	181
	4002-	327	181					4001-	334	182
	4014-	330	181					4015-	332	181
	4026-	335	182					4027-	330	182
	4041-	334	182					4042-	330	181
	4057-	333	182					4058-	331	182
	4074-	332	182					4075-	336	181
90	4091-	336	182				90	4091-	342	182
	4107-	345	182					4106-	350	182

(a) DIGITAL (UNCORRECTED) (b) DIAL (UNCORRECTED) (c) DIGITAL (SMOOTHED)

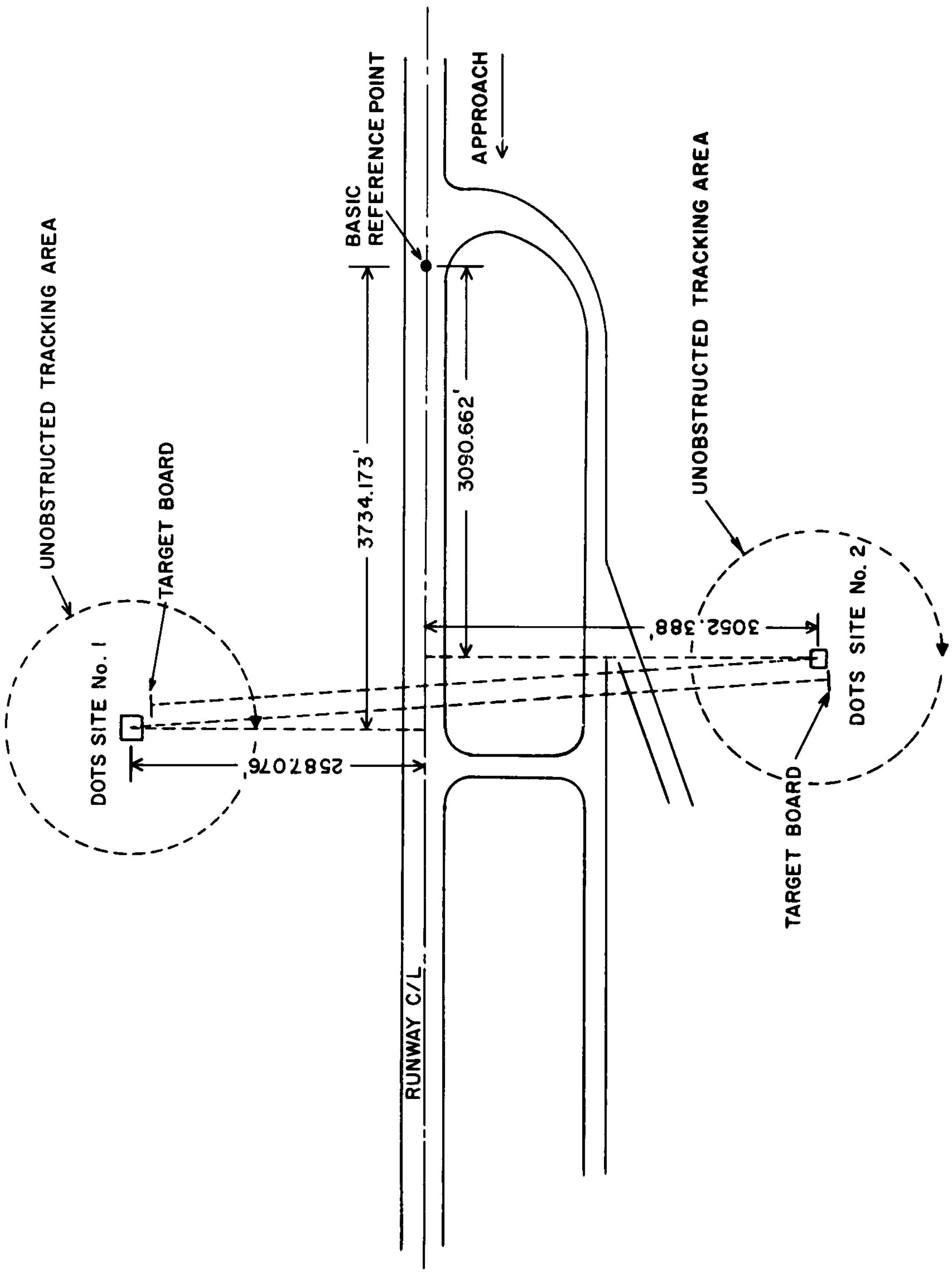


Figure 1. System Geometry

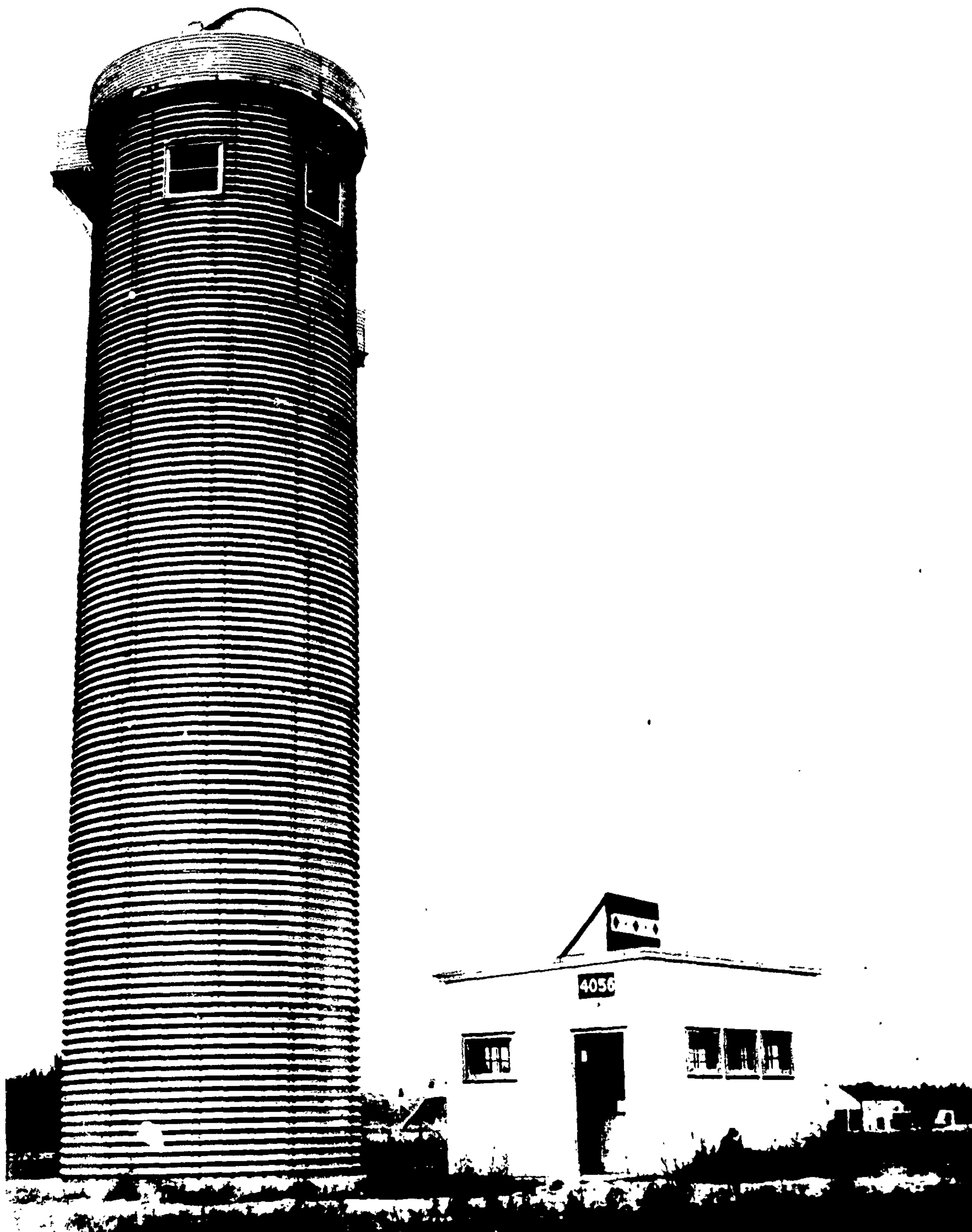


Figure 2. Picture of DOTS Field Station

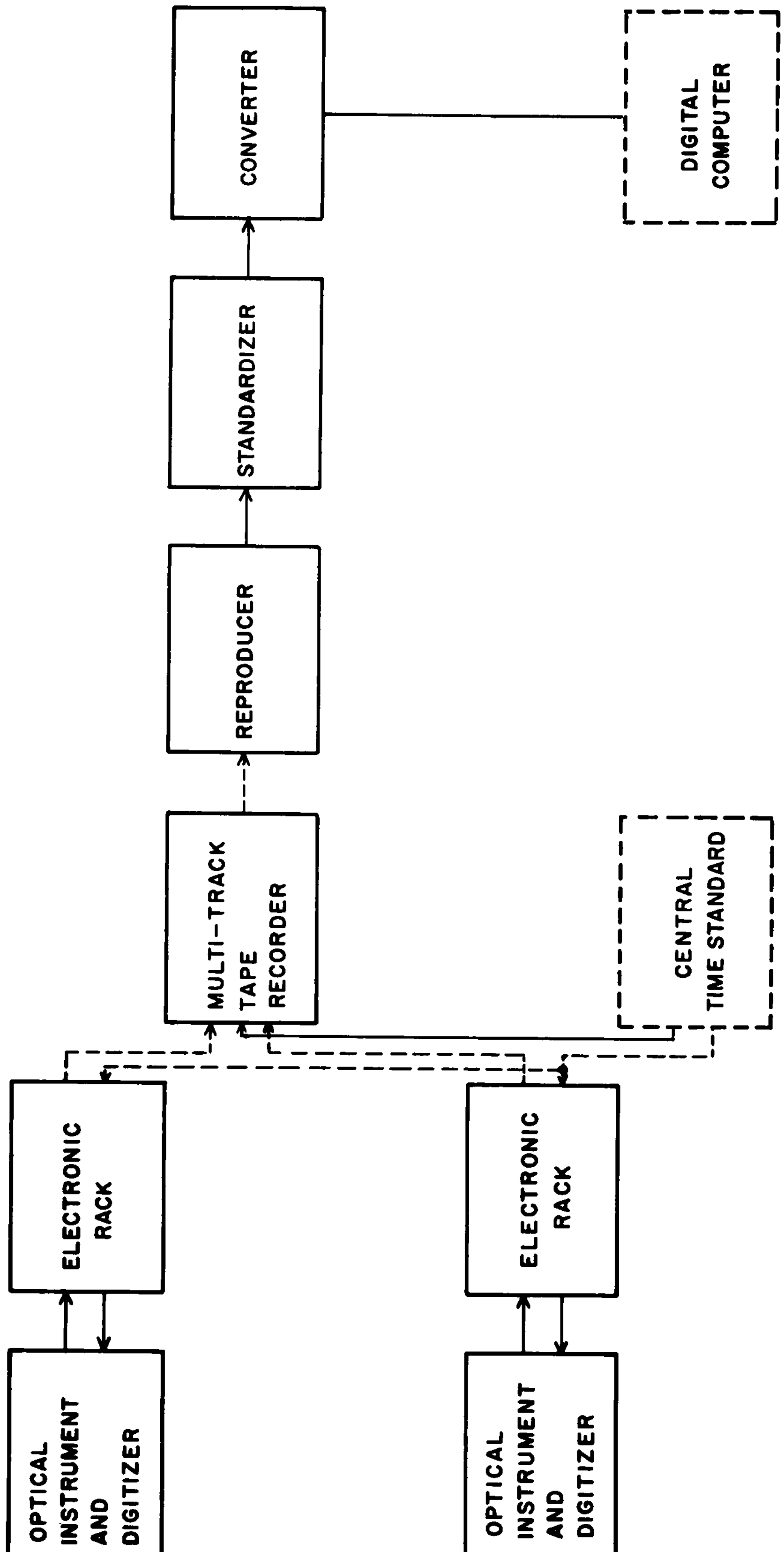


Figure 3. DOTS System Block Diagram

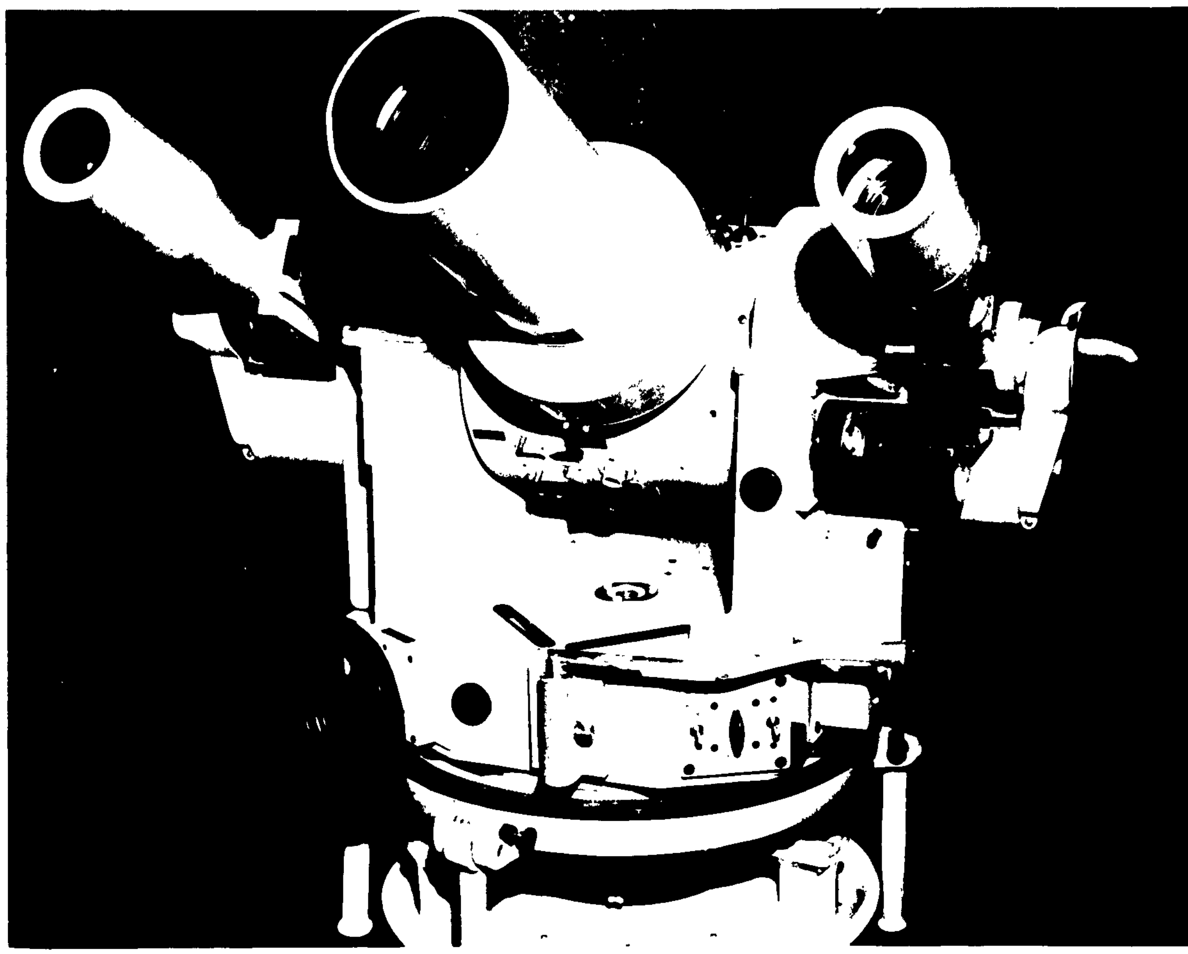


Figure 4. Askania Kth 53 Cine-Theodolite, Complete Modifications

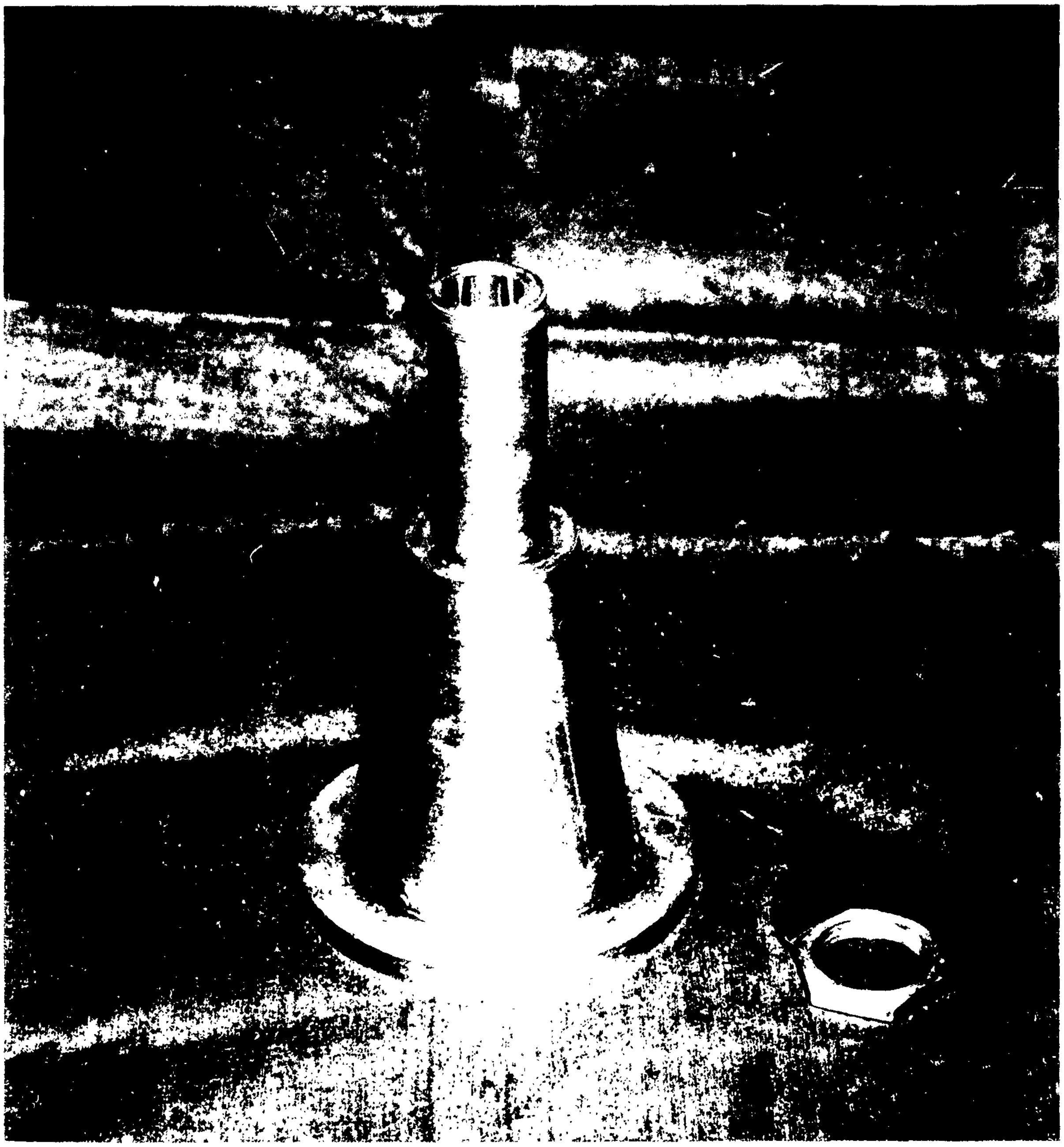


Figure 5. Azimuth Encoder Housing Adapter

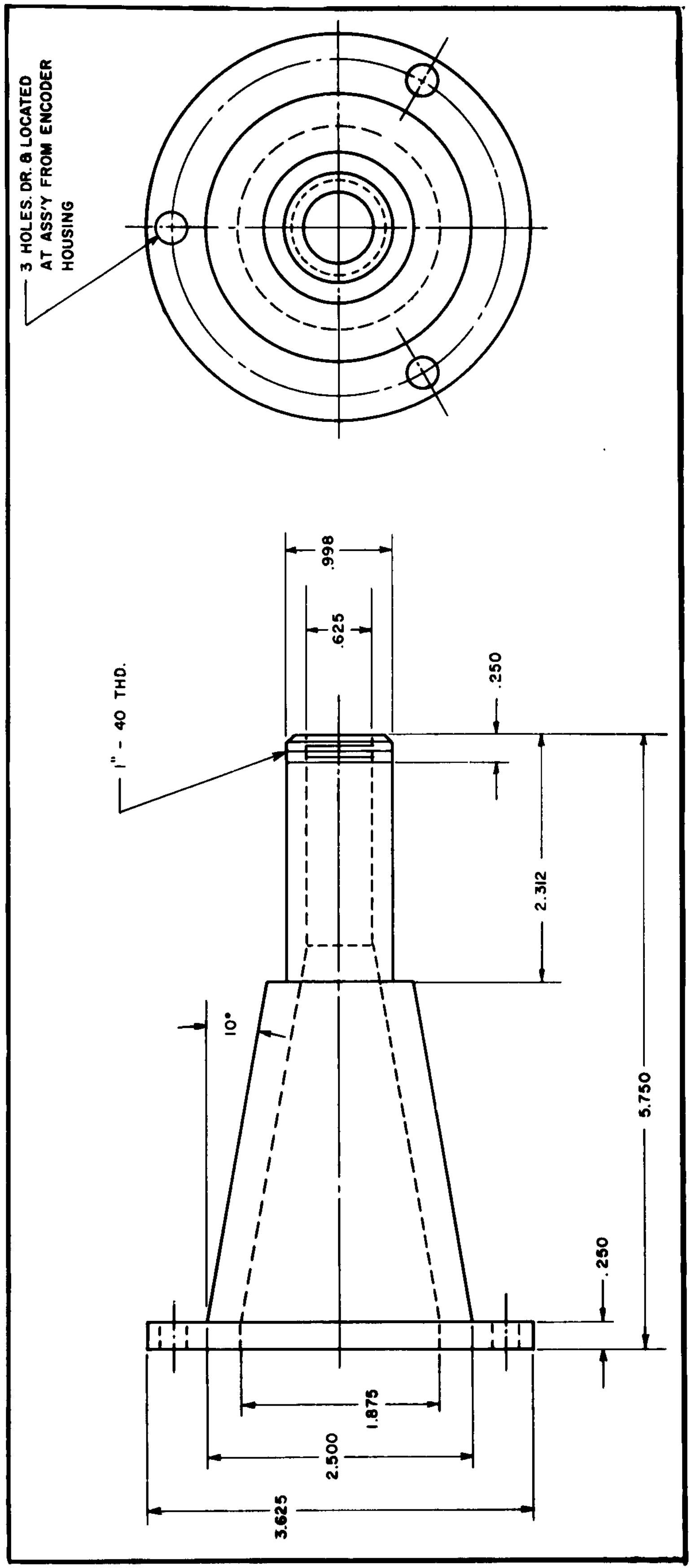


Figure 6. Detail Drawing of Azimuth Encoder Housing Adapter

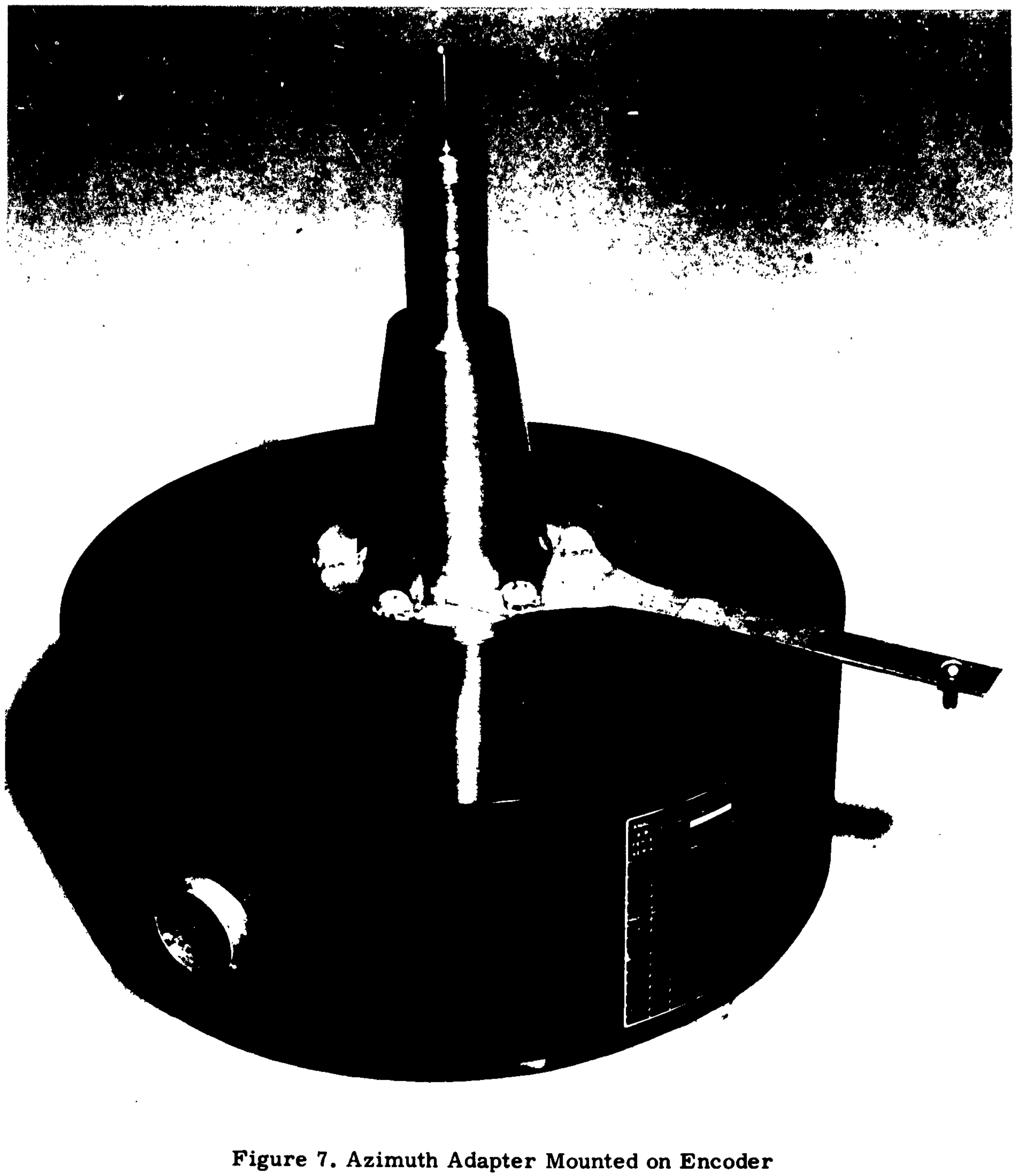


Figure 7. Azimuth Adapter Mounted on Encoder

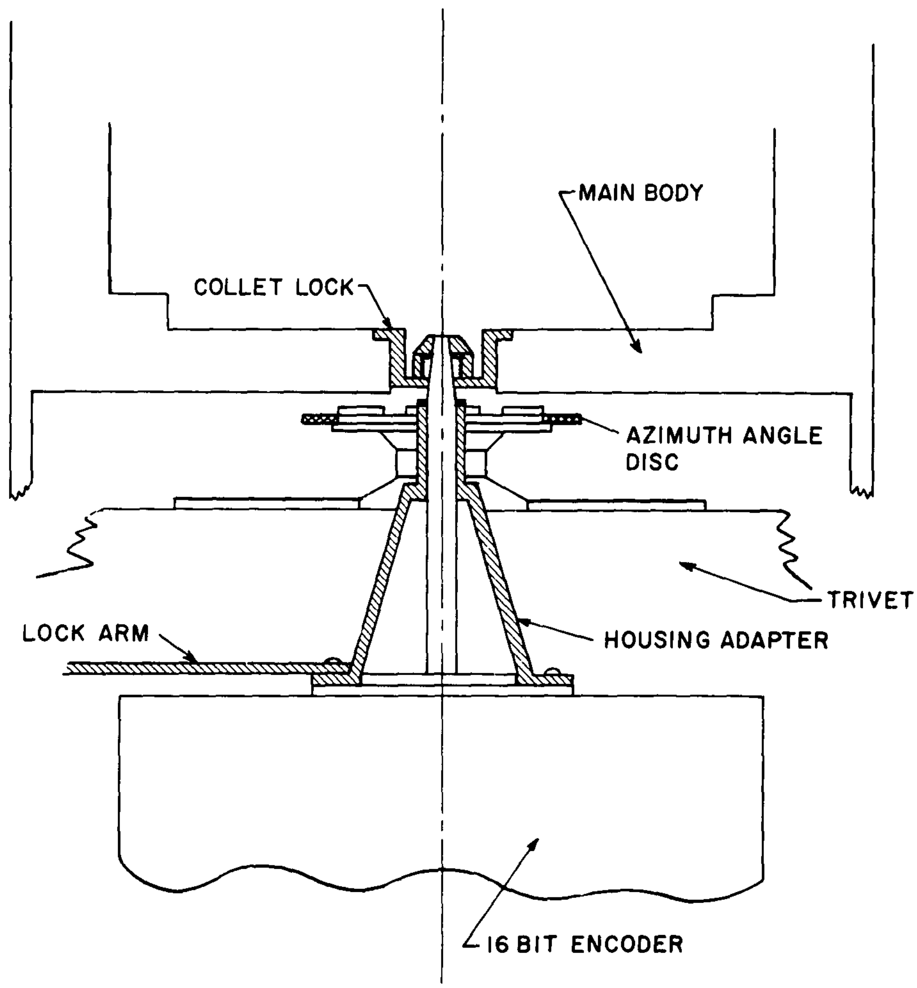


Figure 8. Profile of Azimuth Encoder Mounting to Askania Instrument

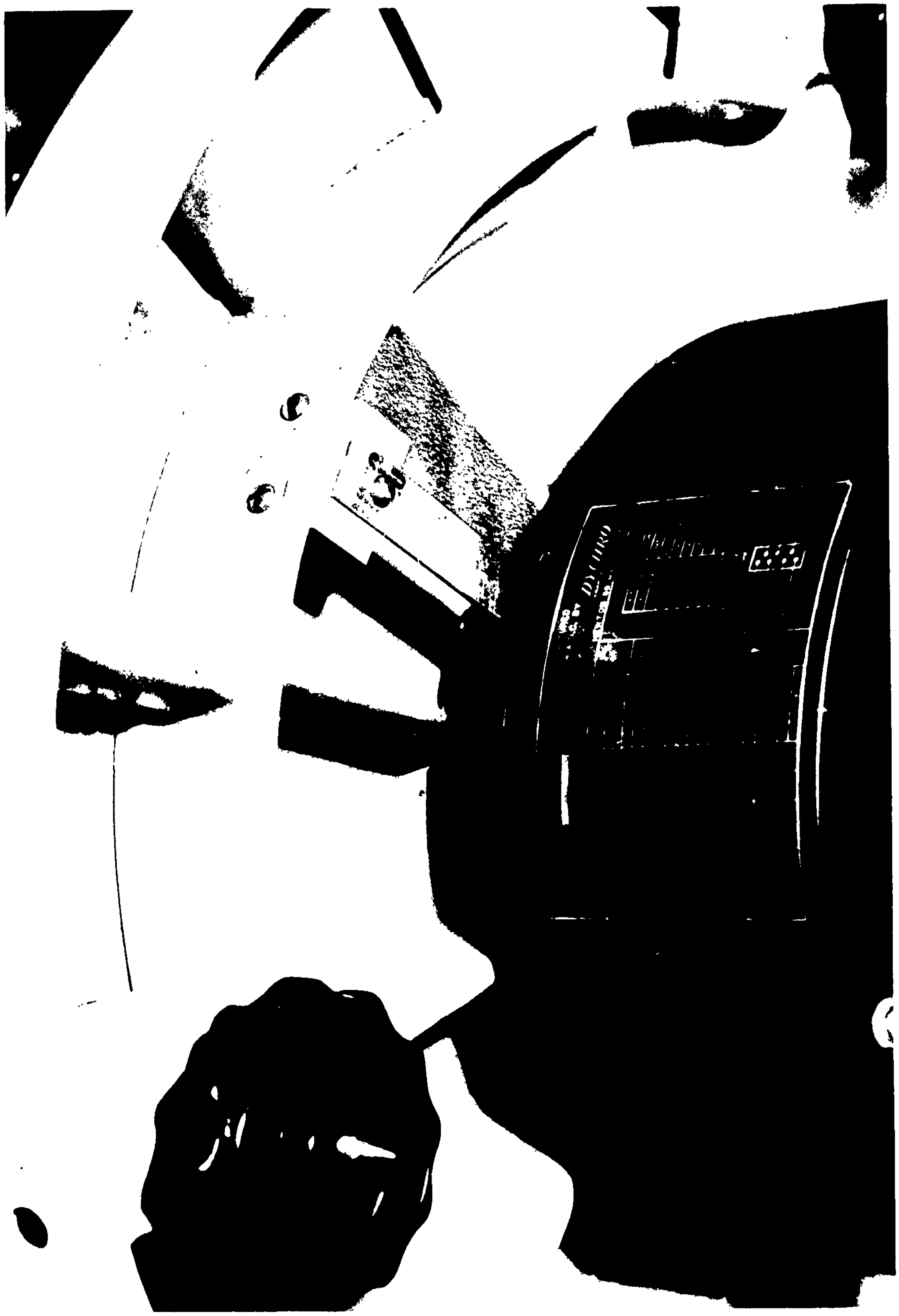


Figure 9. Azimuth Encoder Attached to Trivet

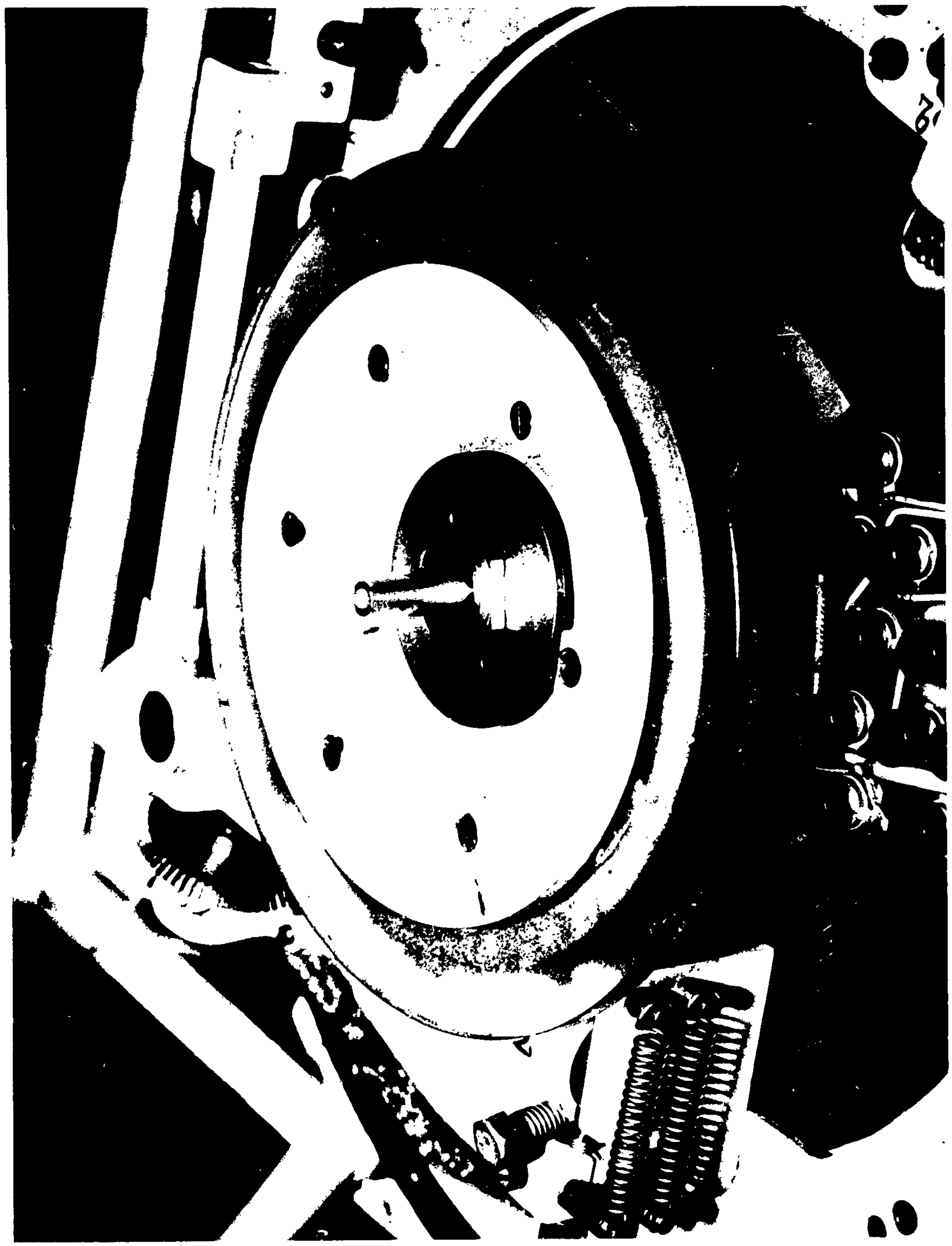


Figure 10. Azimuth Encoder Lock-Nut Assembled

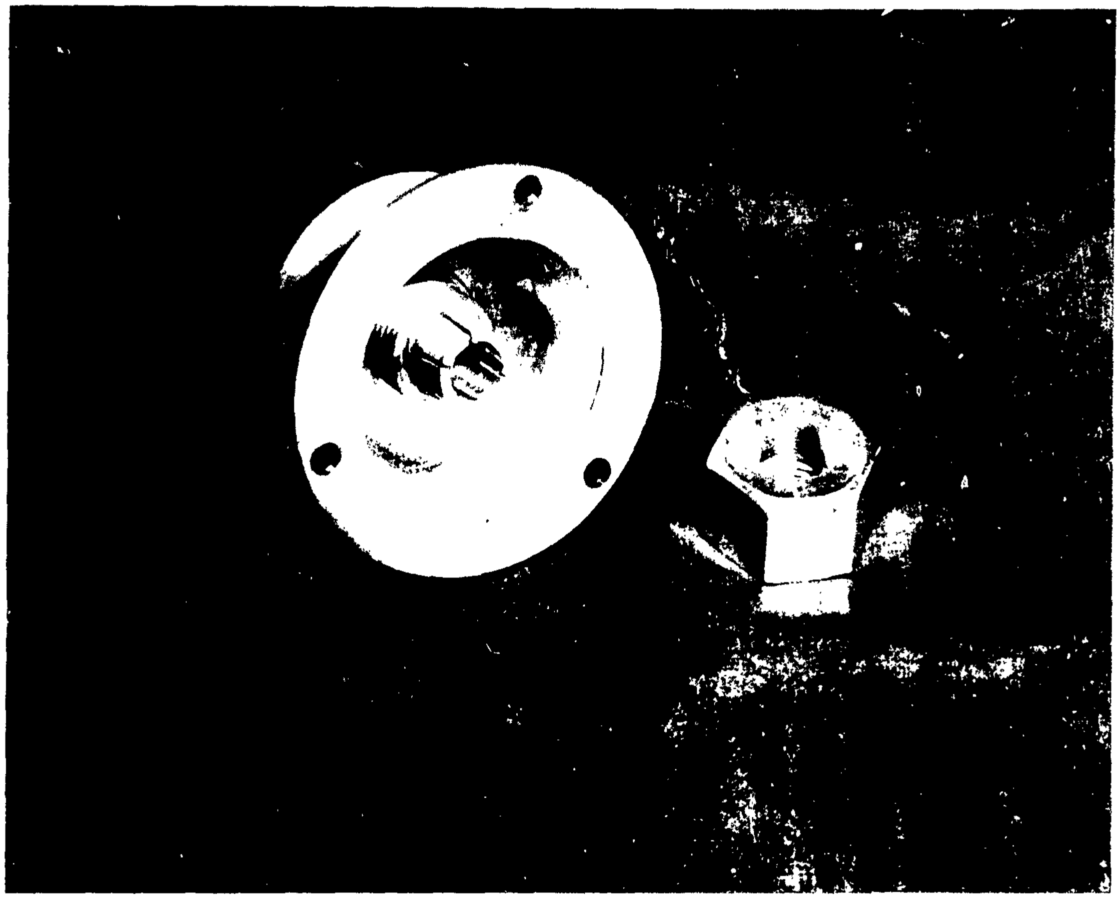


Figure 11. Coupling Collet Lock

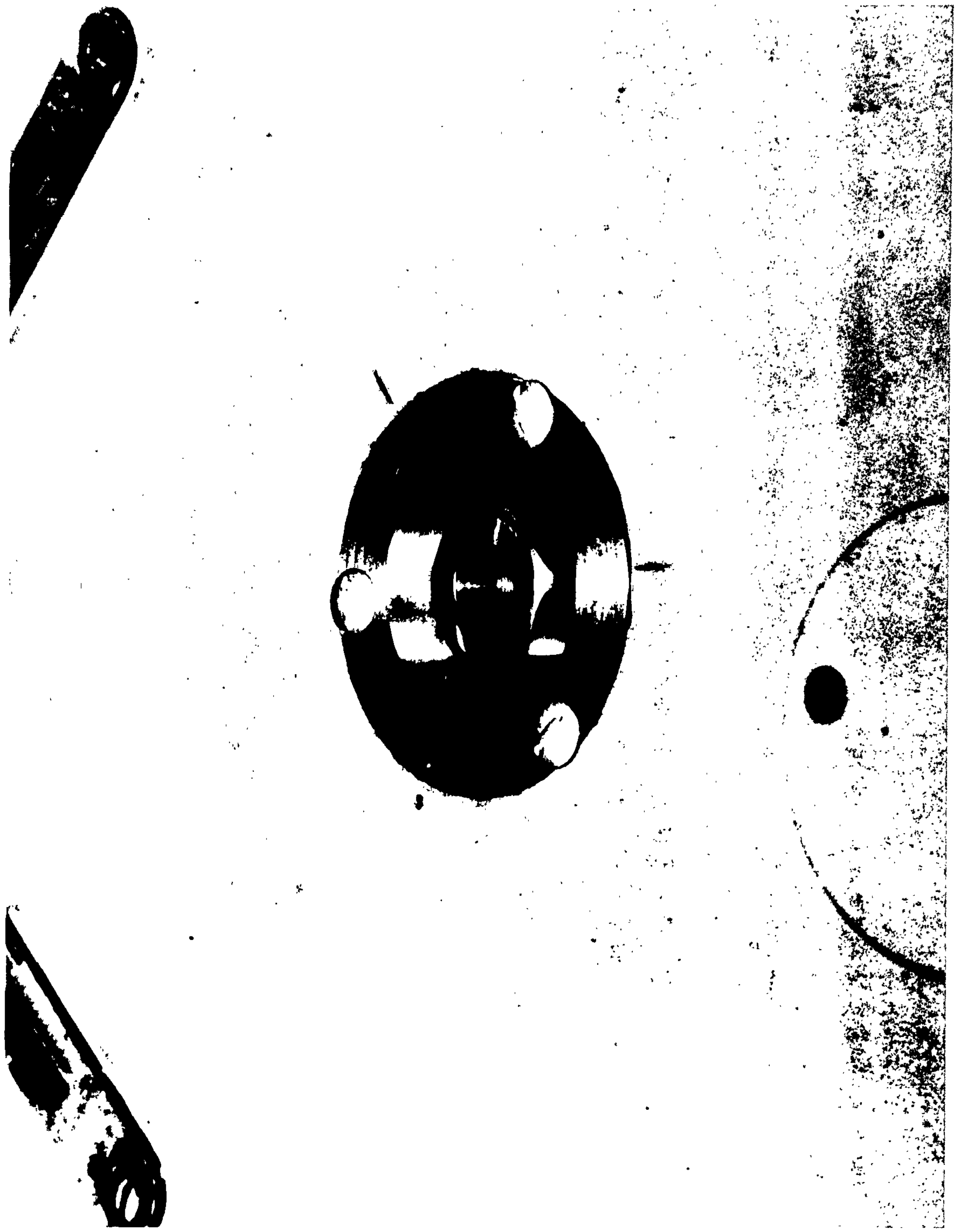


Figure 12. Coupling Collet Lock Installed

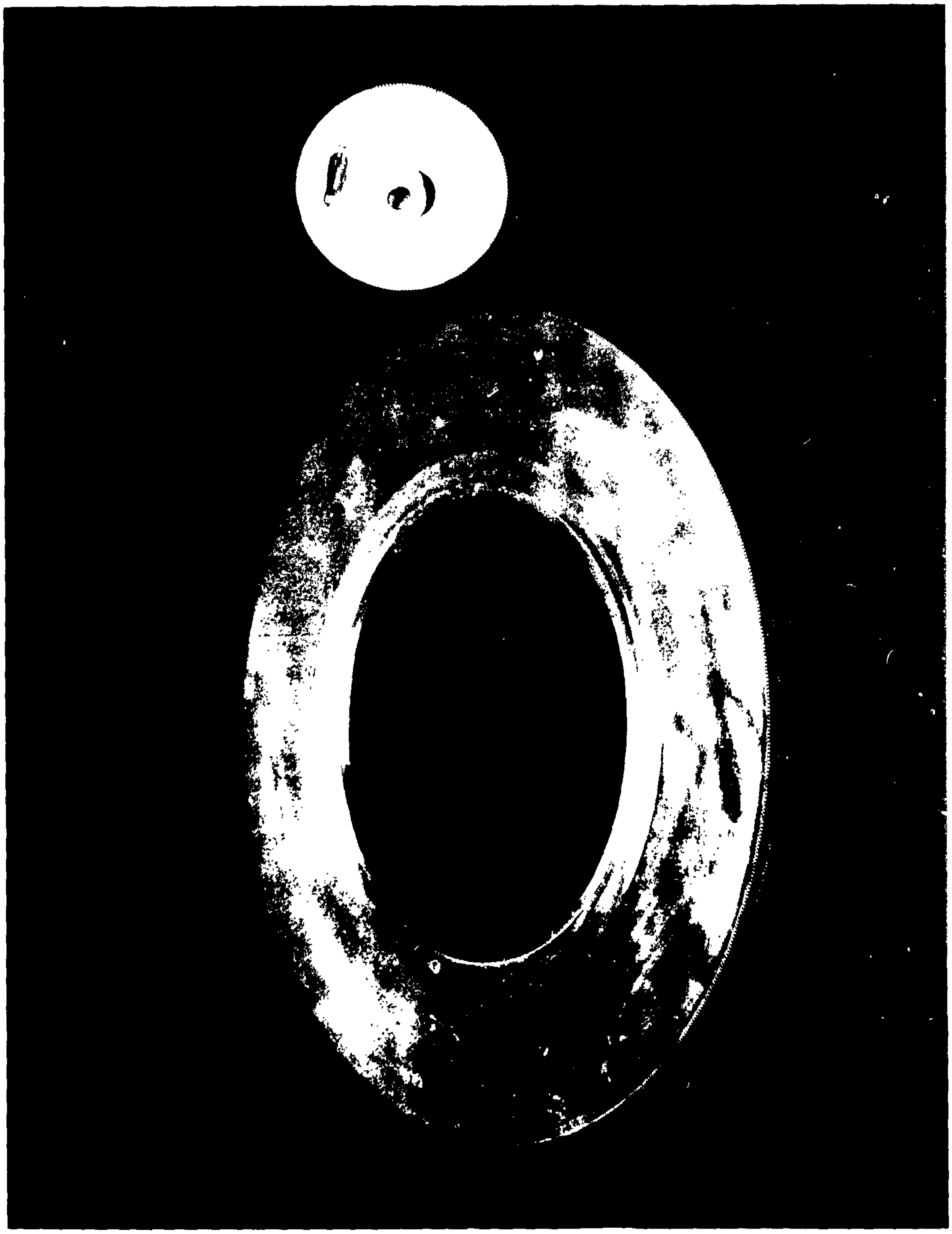


Figure 13. Elevation Encoder Coupling Gears

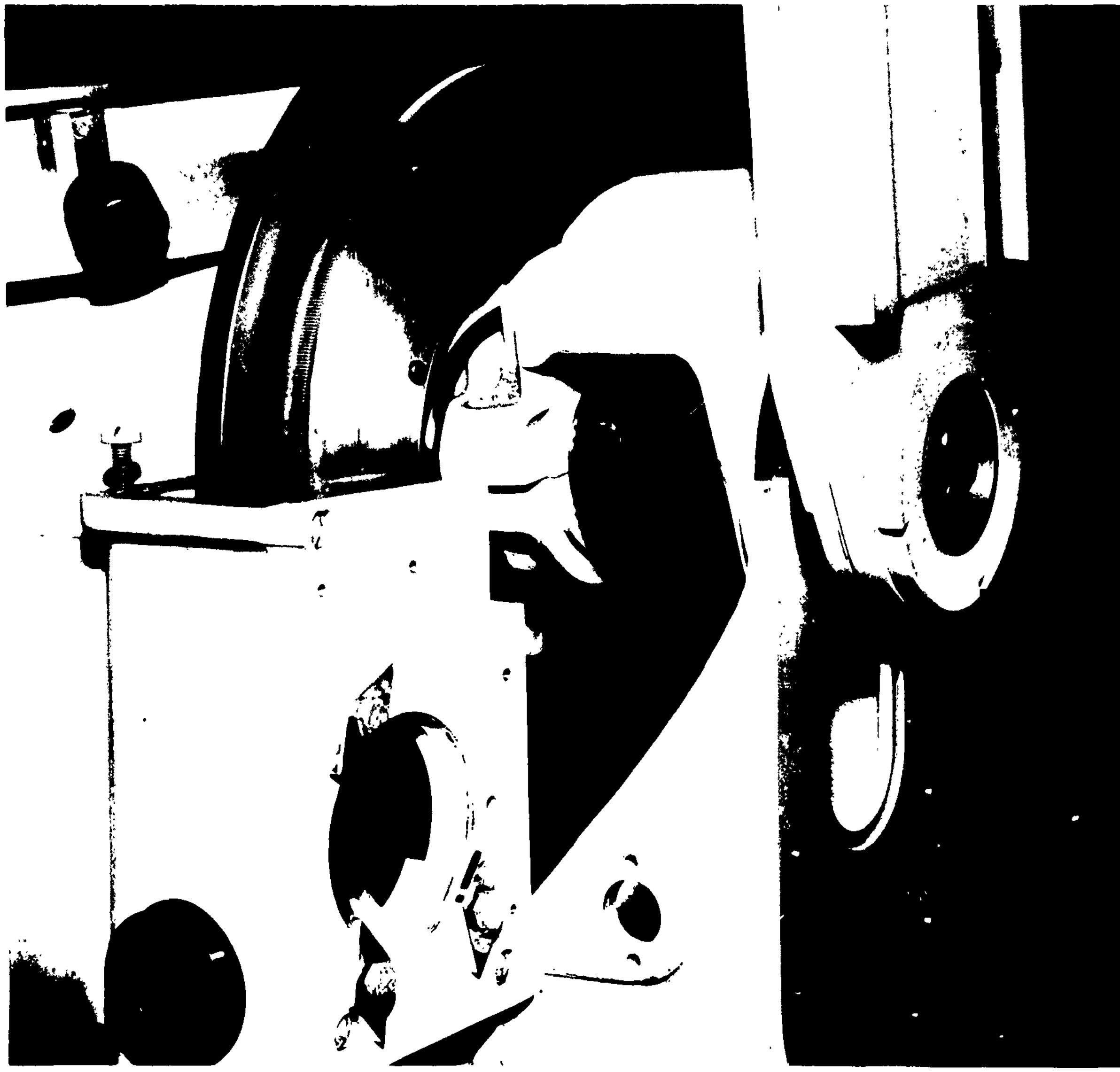


Figure 14. Ring Gear Mounting in Elevation Optical Train and Encoder Support Adapter Plate

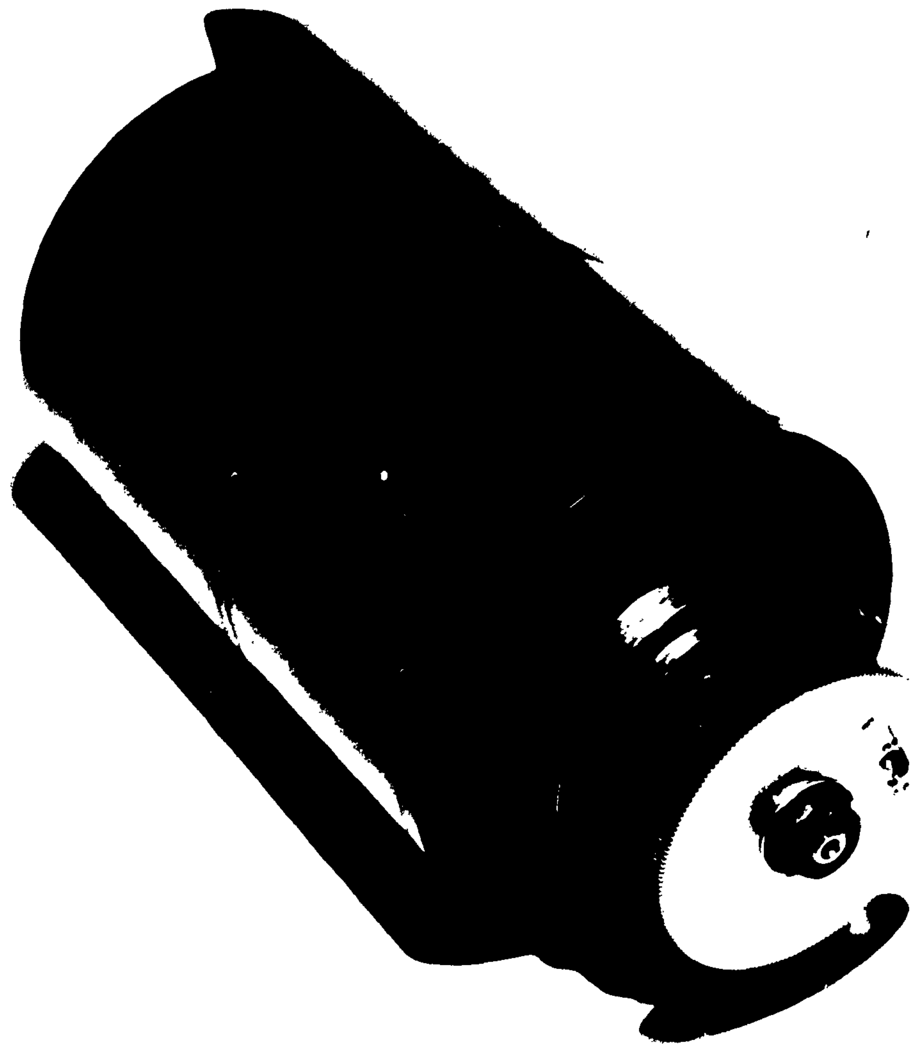


Figure 15. Pinion Split Gear Encoder Assembled

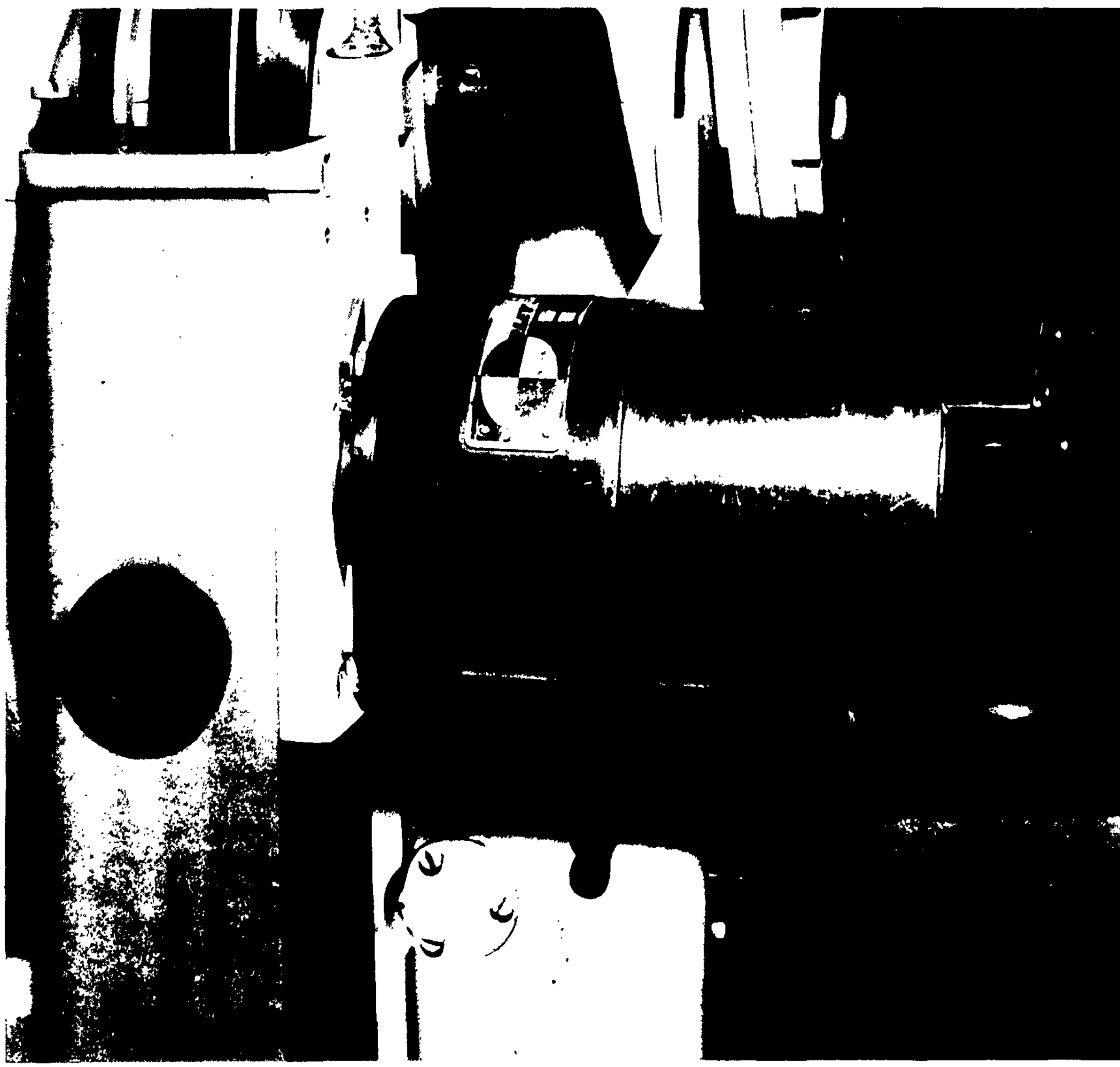


Figure 16. Elevation Encoder Attached to Adapter Plate

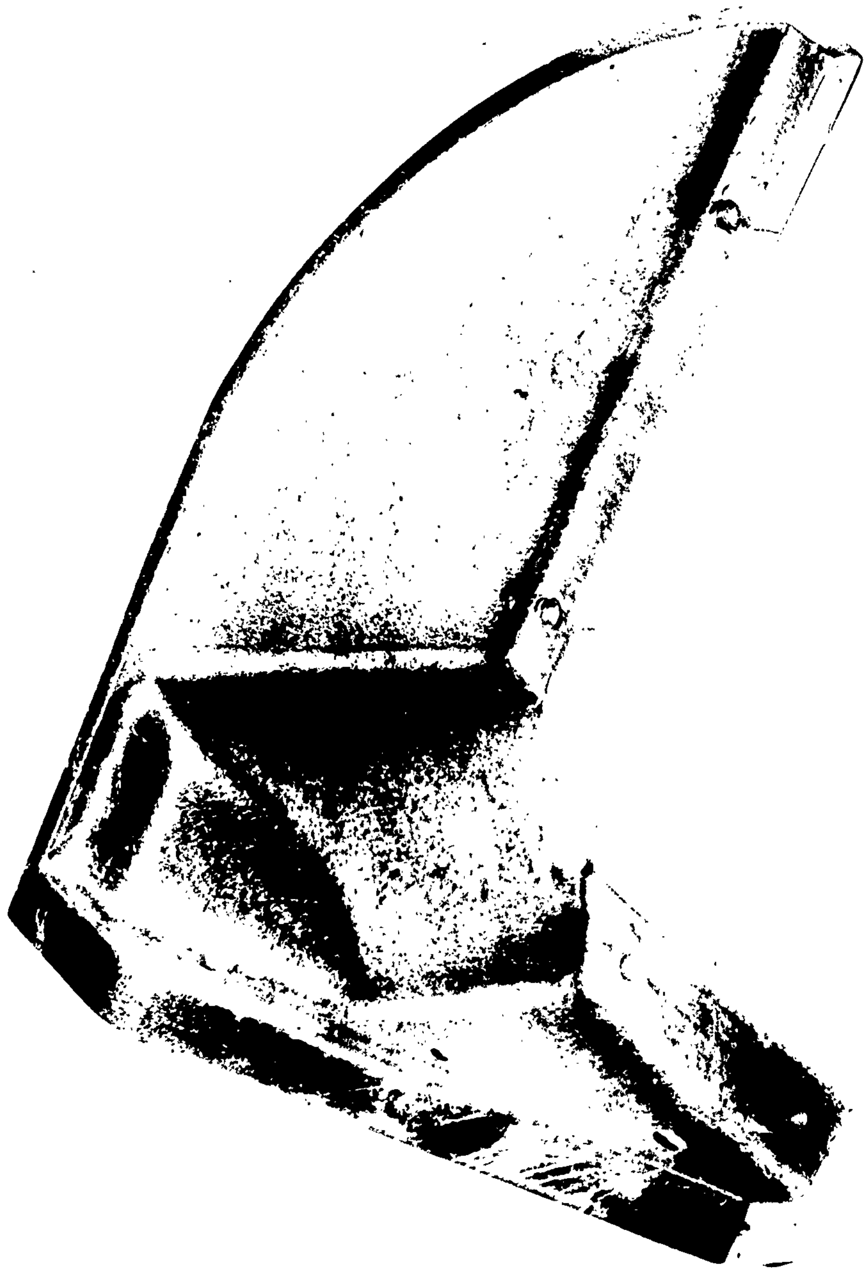


Figure 17. Casting for Protective Covers

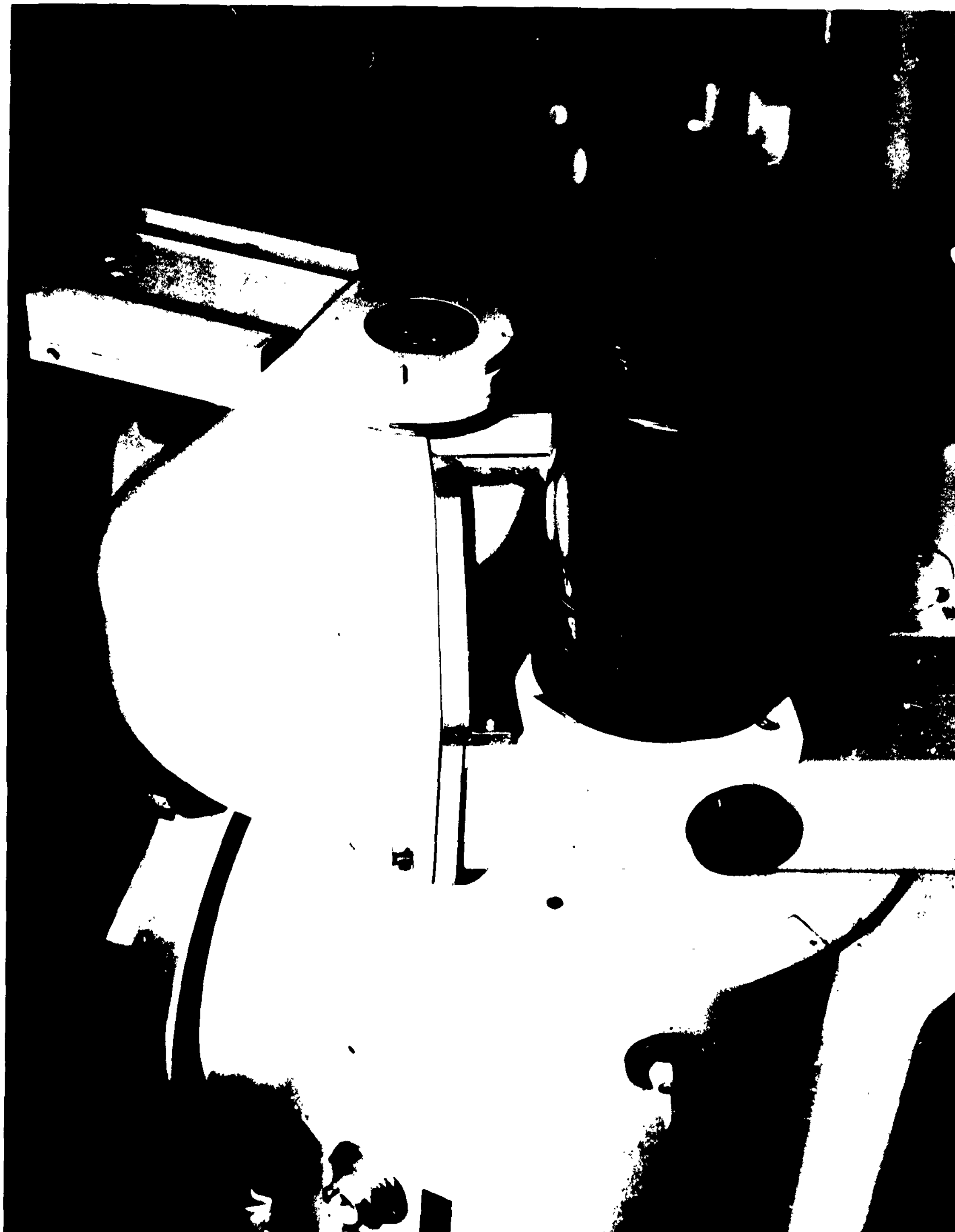


Figure 18. Final Assembly of Elevation Encoder

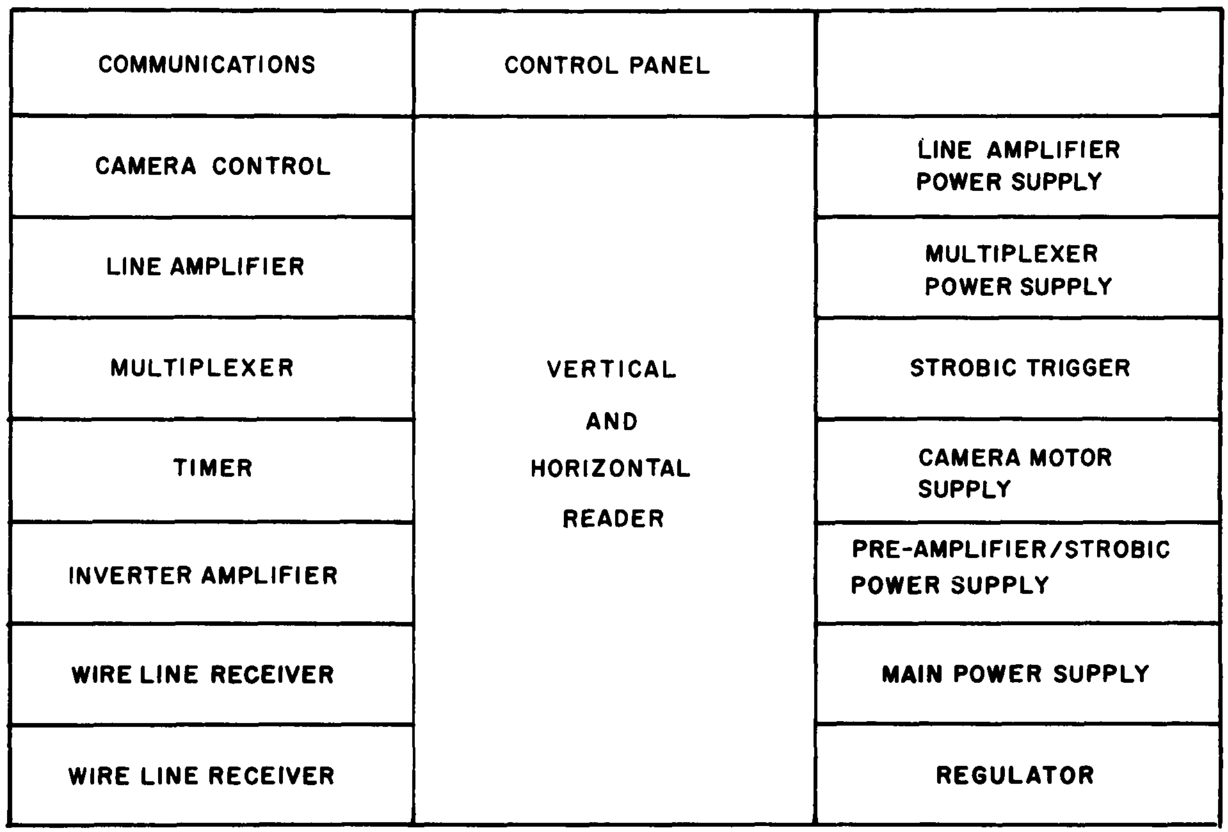


Figure 19. Field Station Electronic Rack Detailed Layout

1

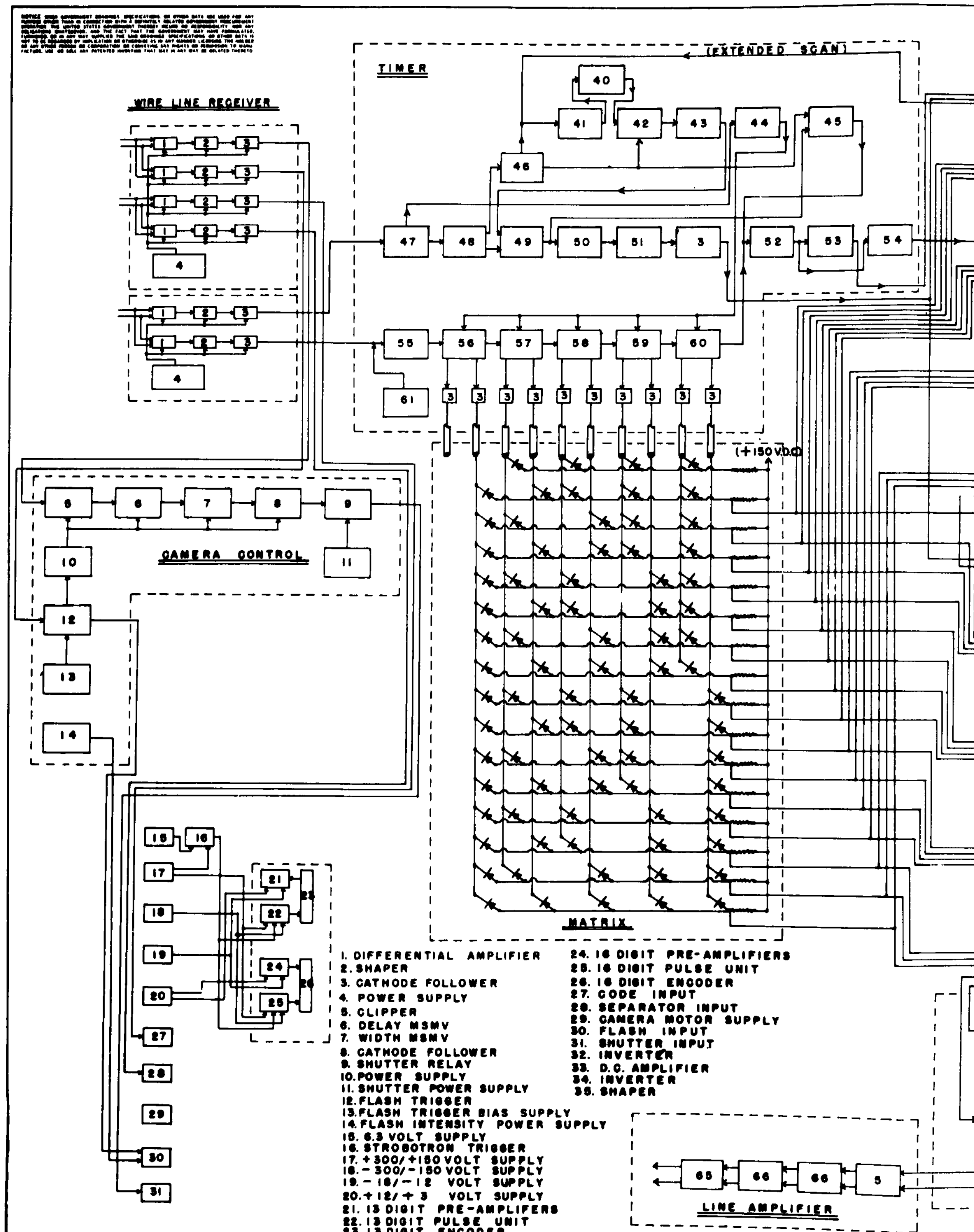
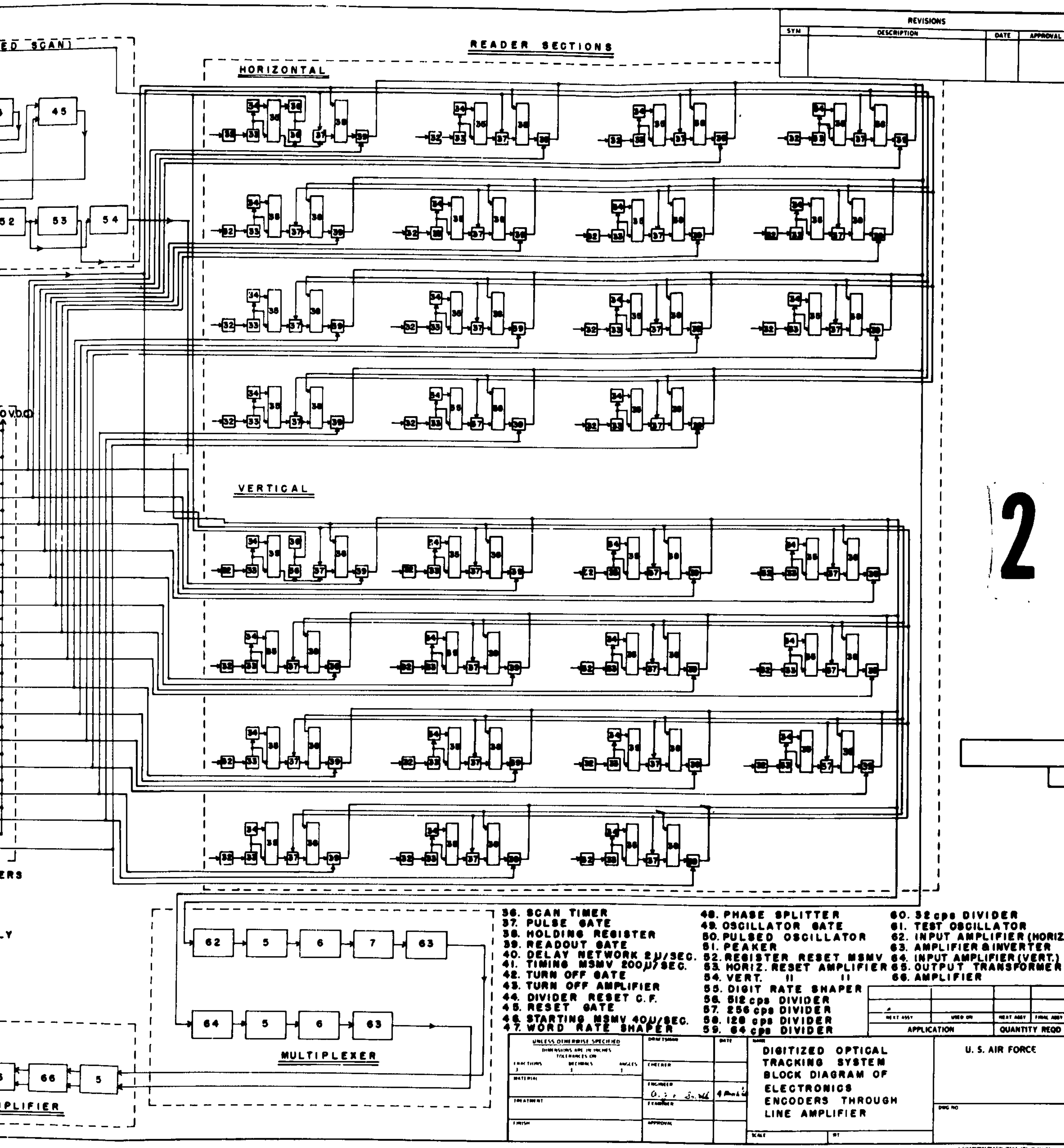


Figure 20. Block Diagram of Fiel



Block Diagram of Field Station Electronics

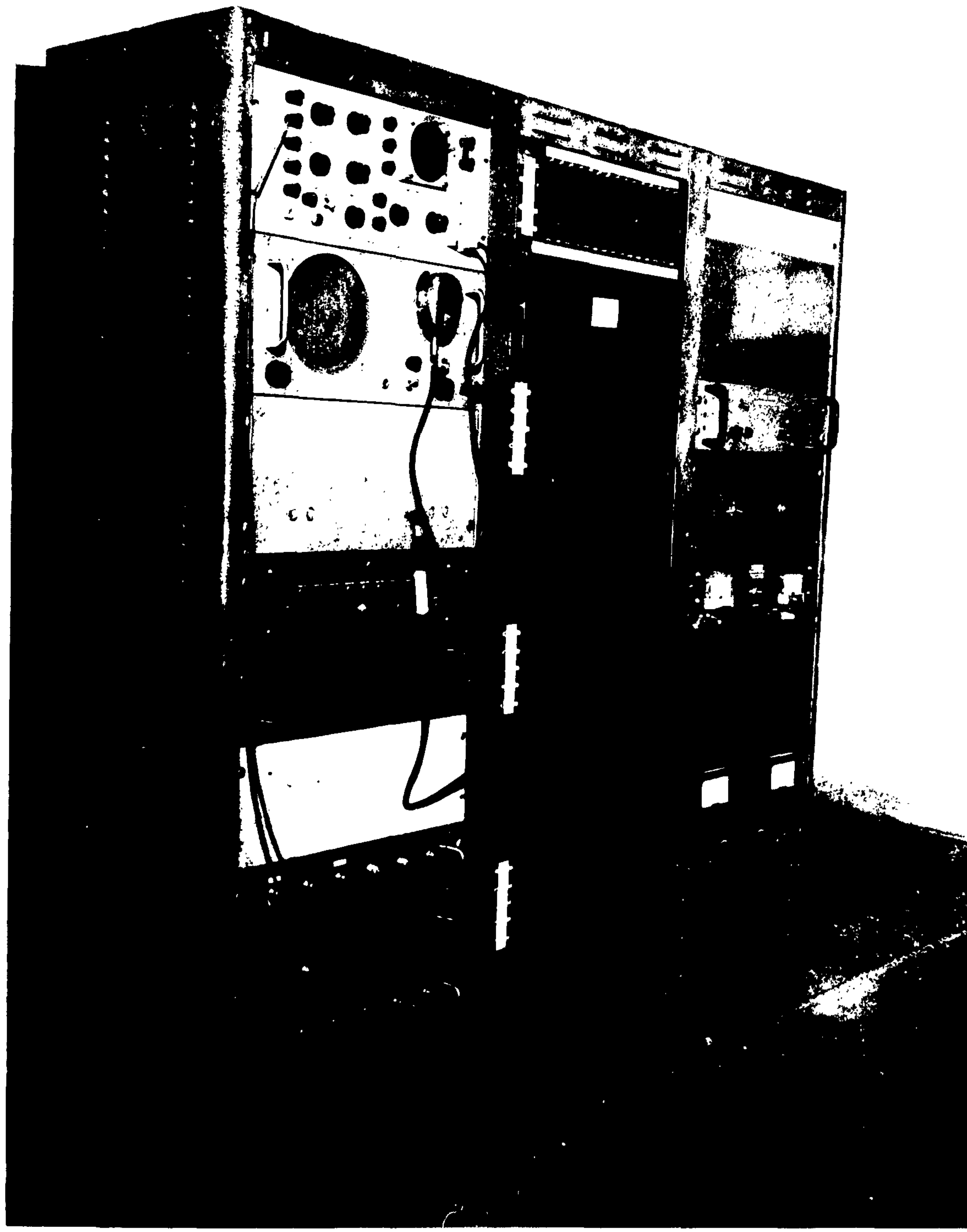


Figure 21. Front View of Field Station Electronic Racks

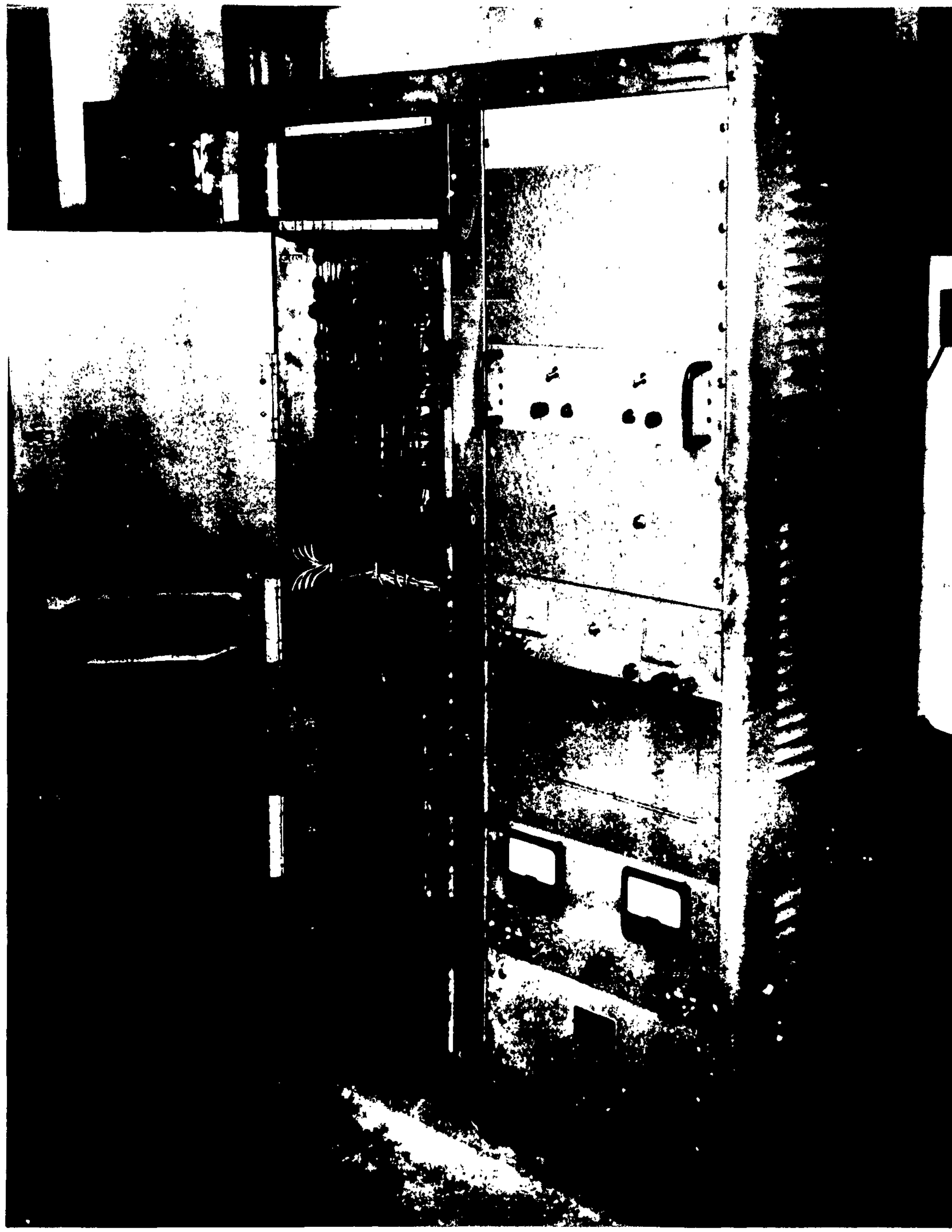


Figure 22. Rear View of Reader and Matrix Section

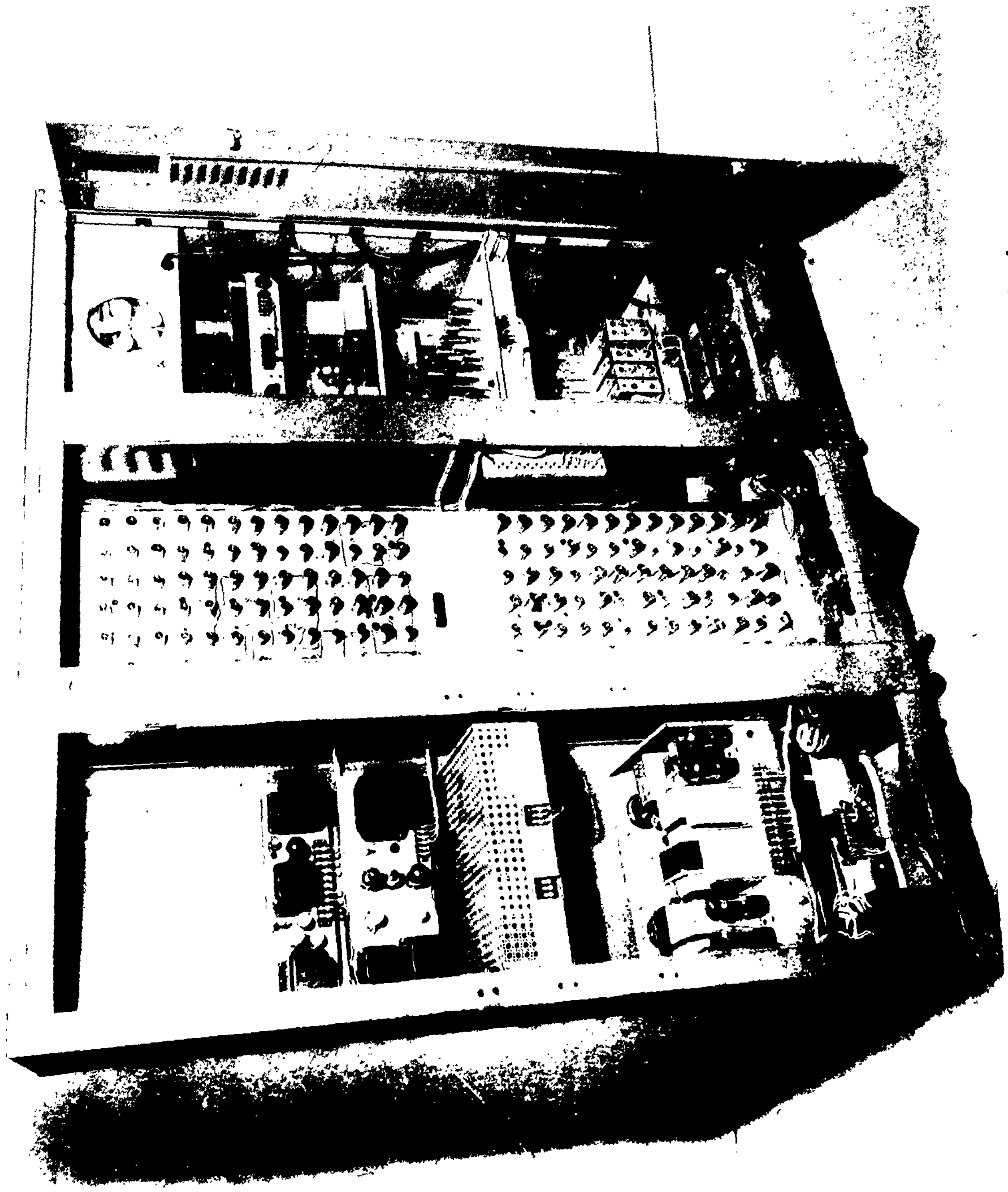


Figure 23. Rear View of Field Station Electronic Racks

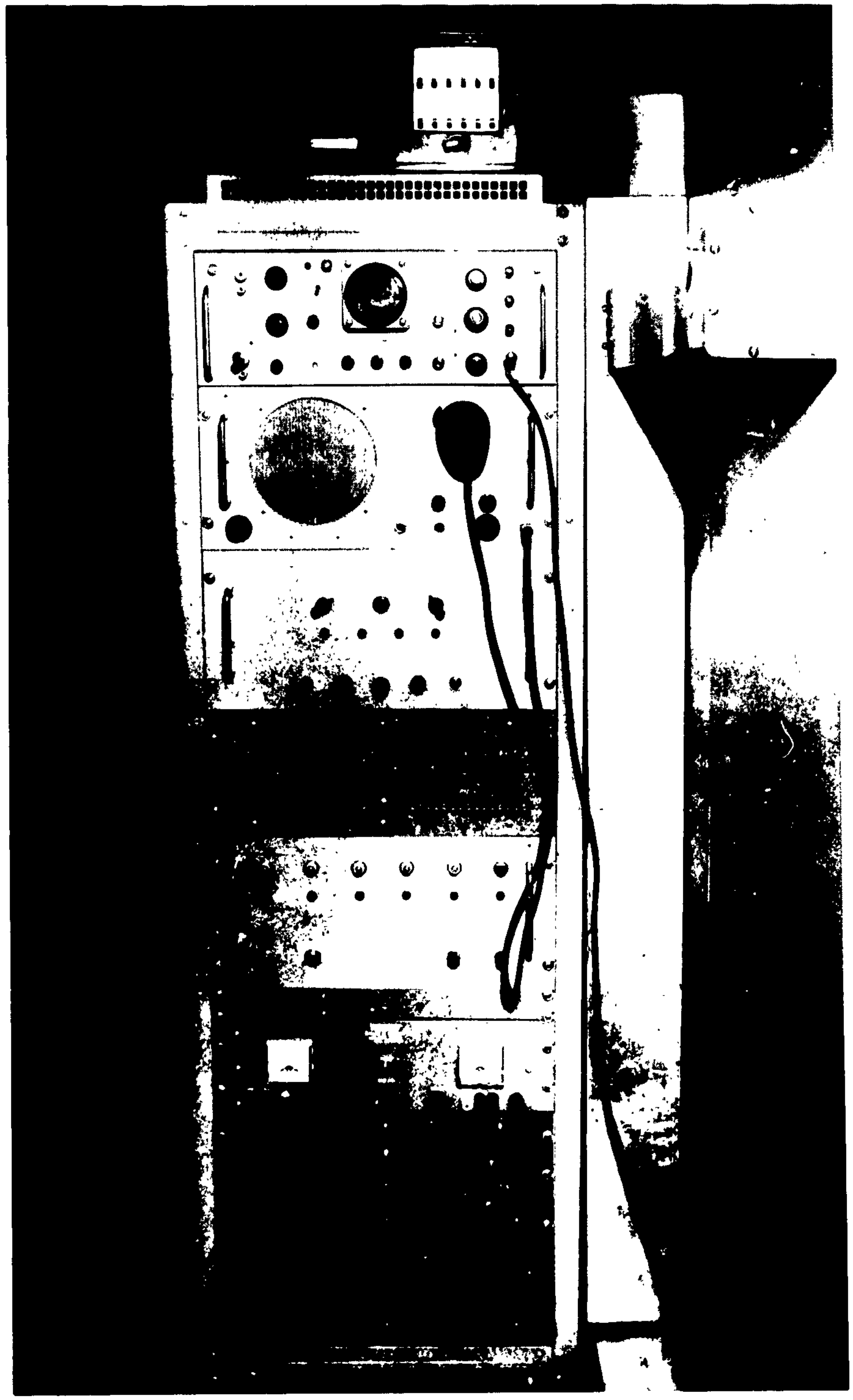


Figure 24. Front View of Auxiliary Rack at DOTS No. 1

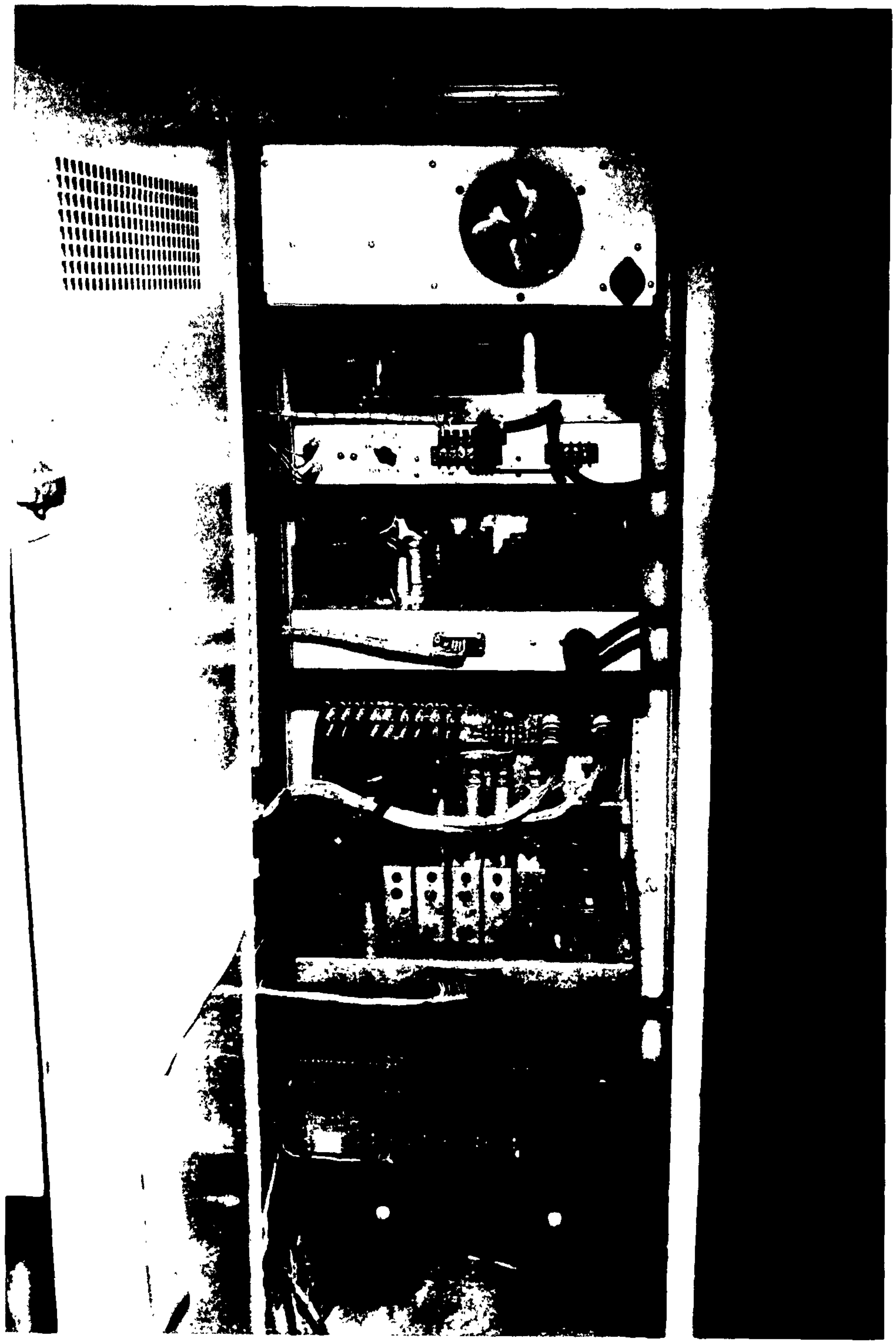


Figure 25. Rear View of Auxiliary Rack at DOTS No. 1

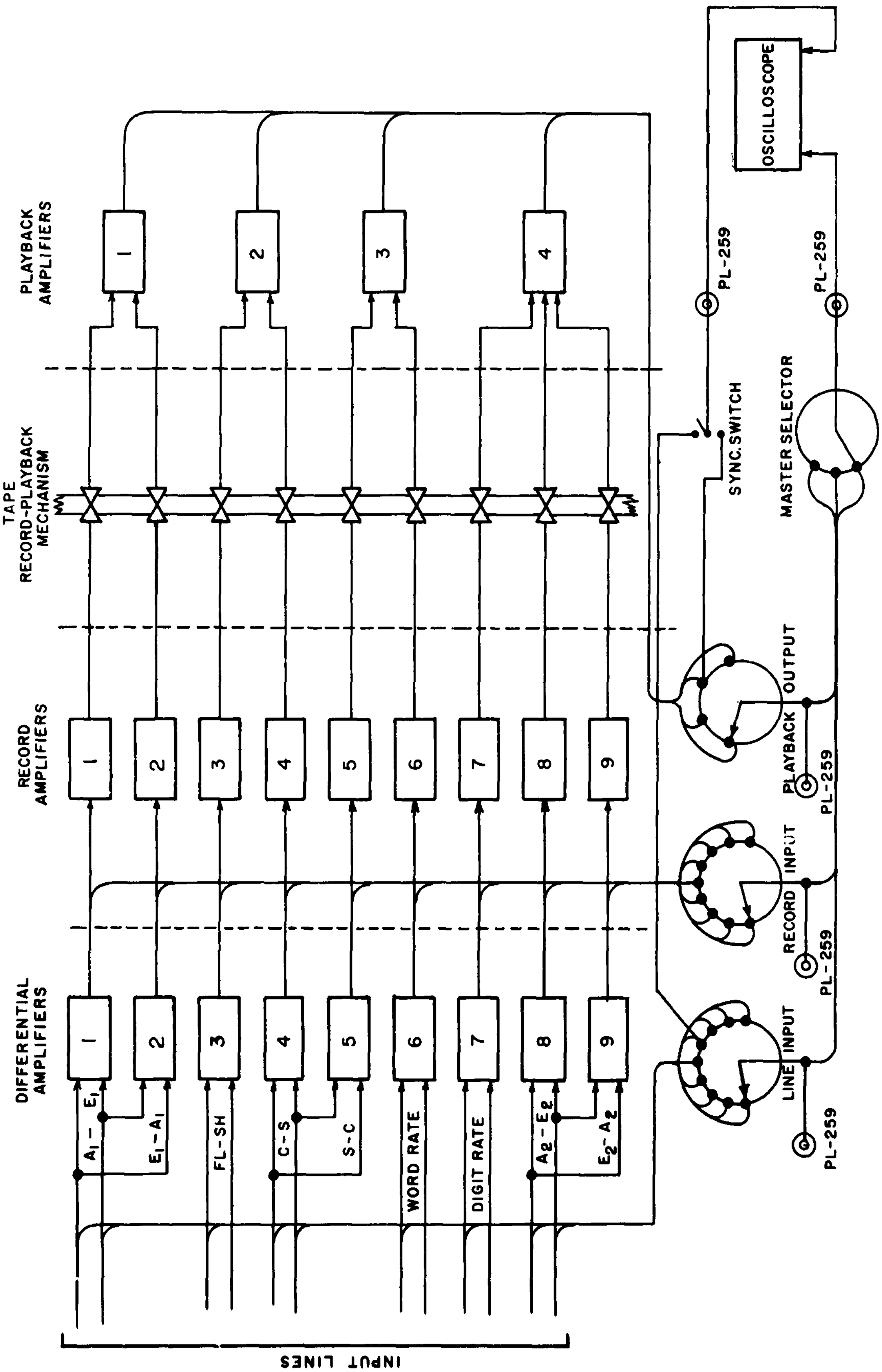


Figure 26. Block Diagram of Central Recorder Subsystem

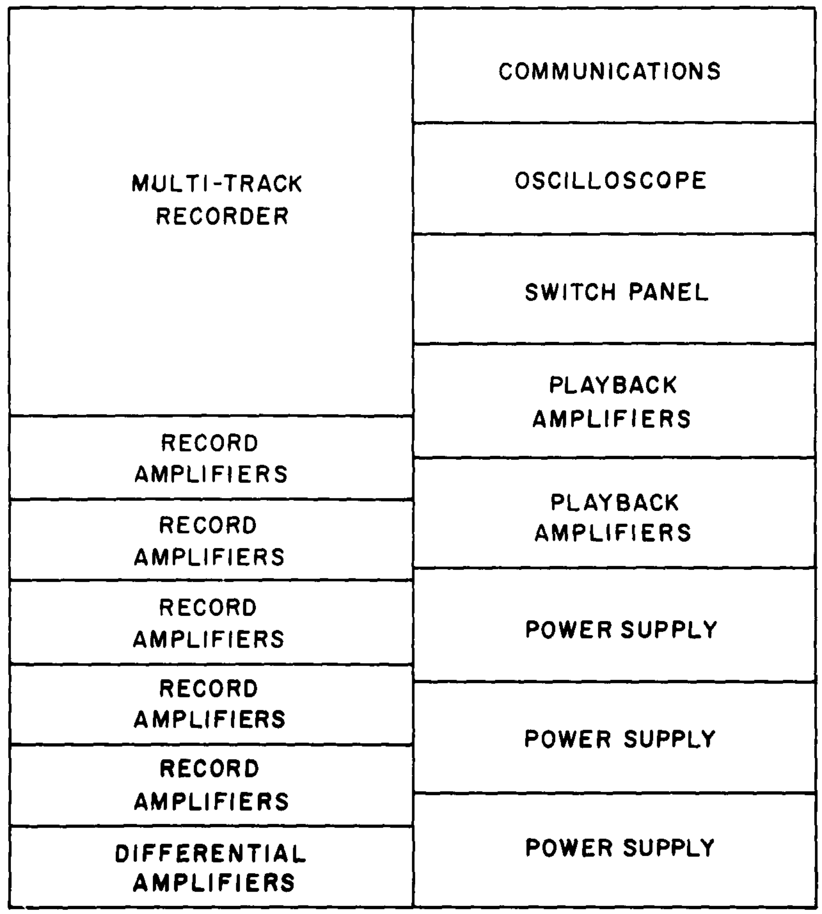


Figure 27. Central Recorder Rack Detail Layout

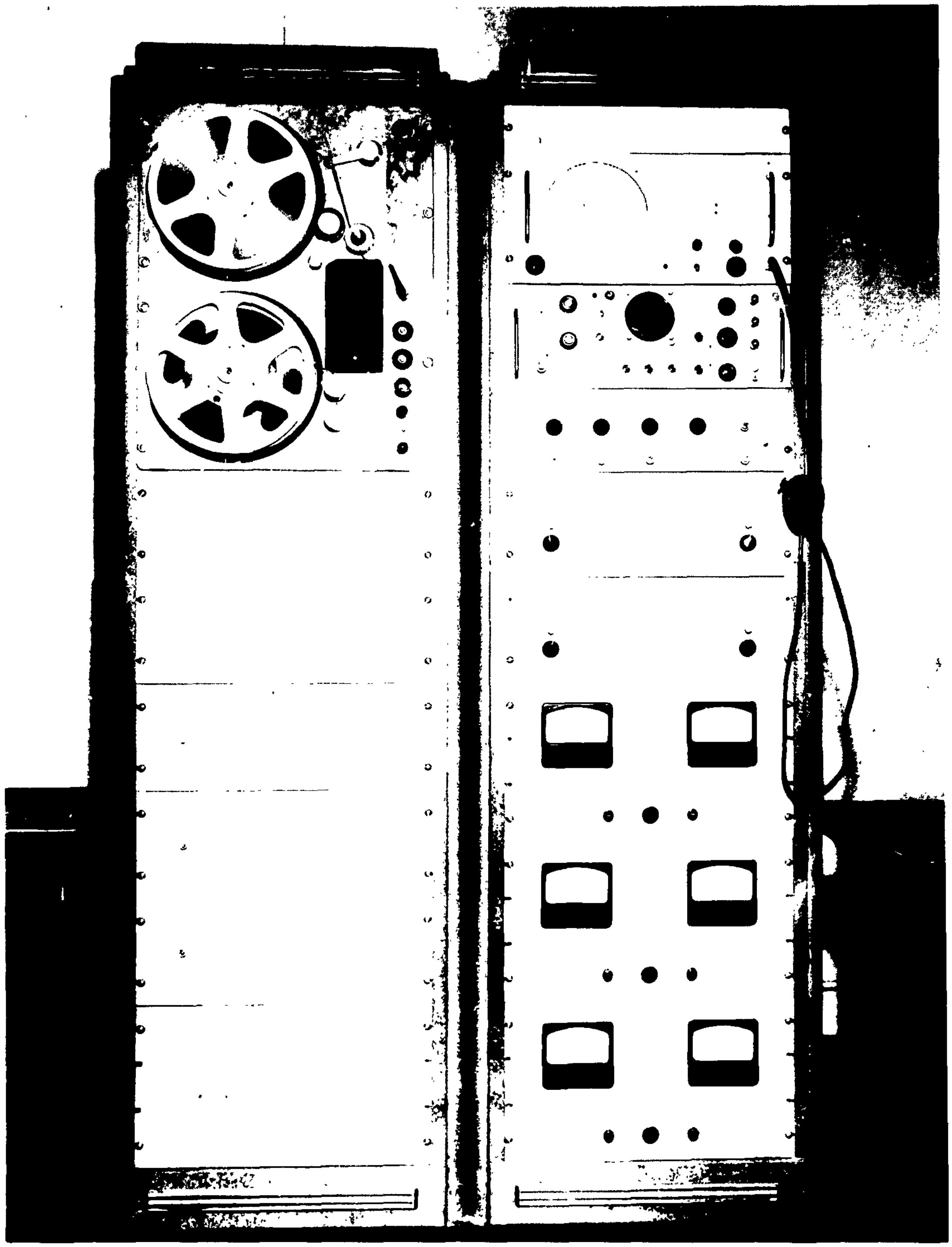


Figure 28. Picture of Central Recorder Subsystem

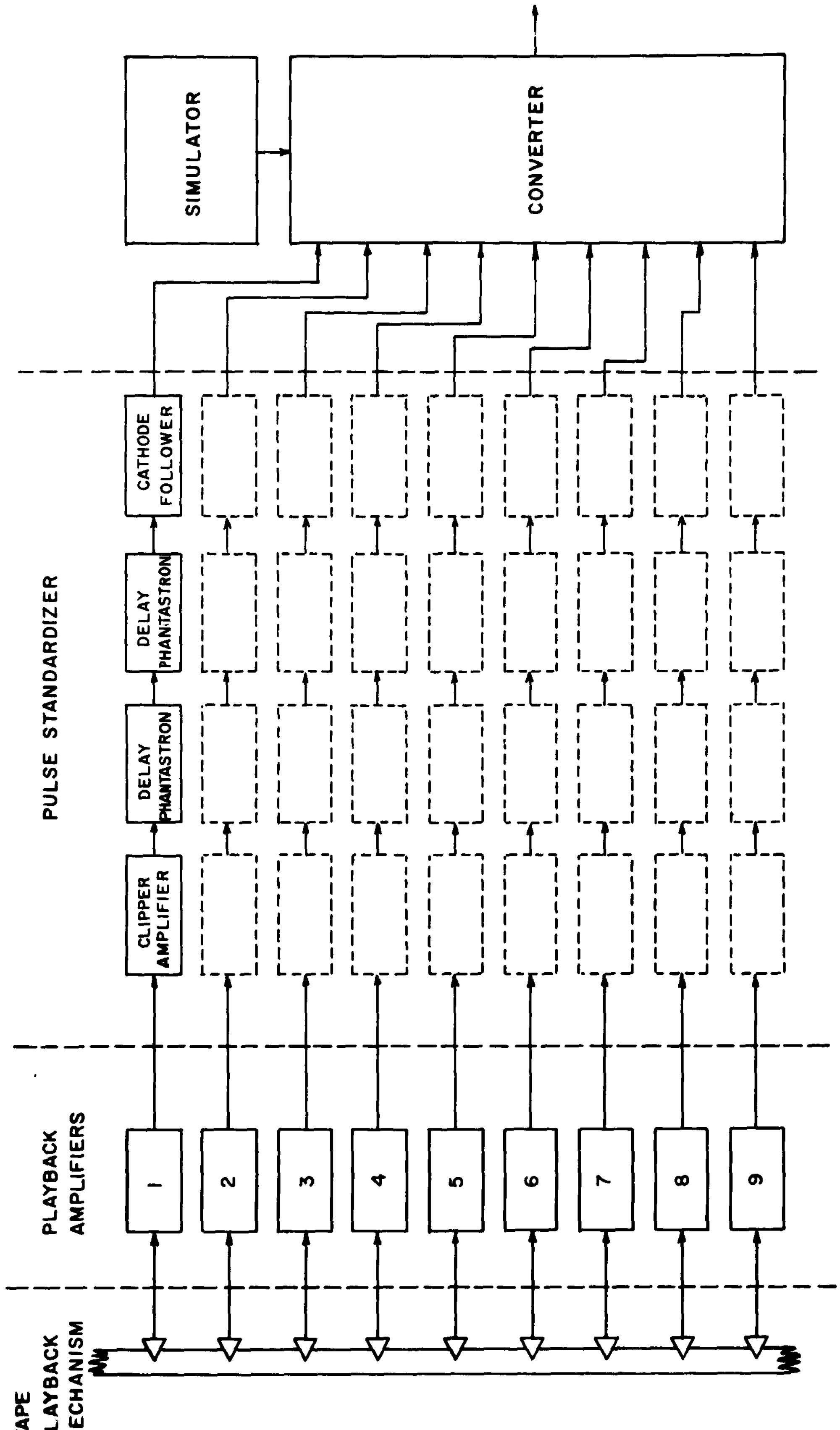


Figure 29. Block Diagram of Playback and Converter Subsystem

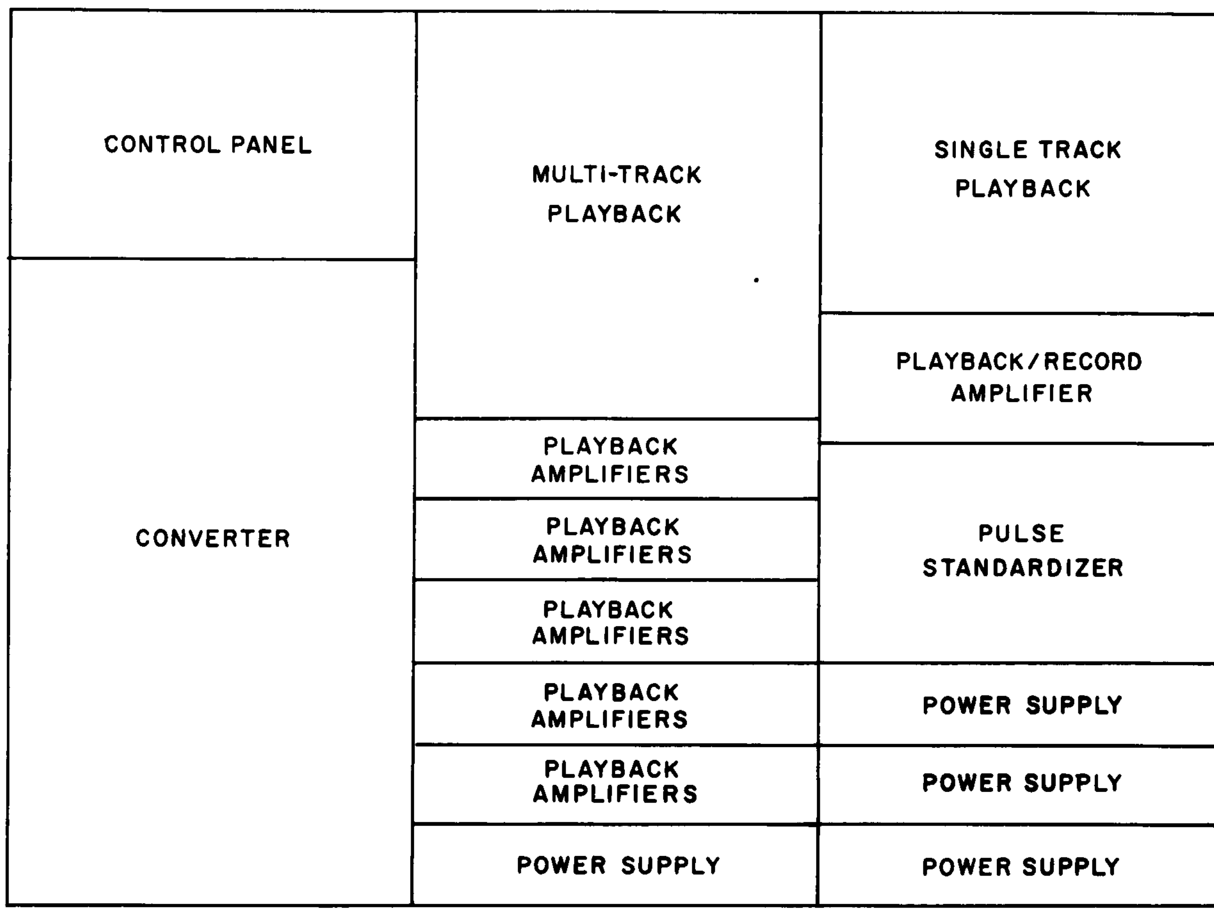


Figure 30. Playback and Converter Rack Detail Layout

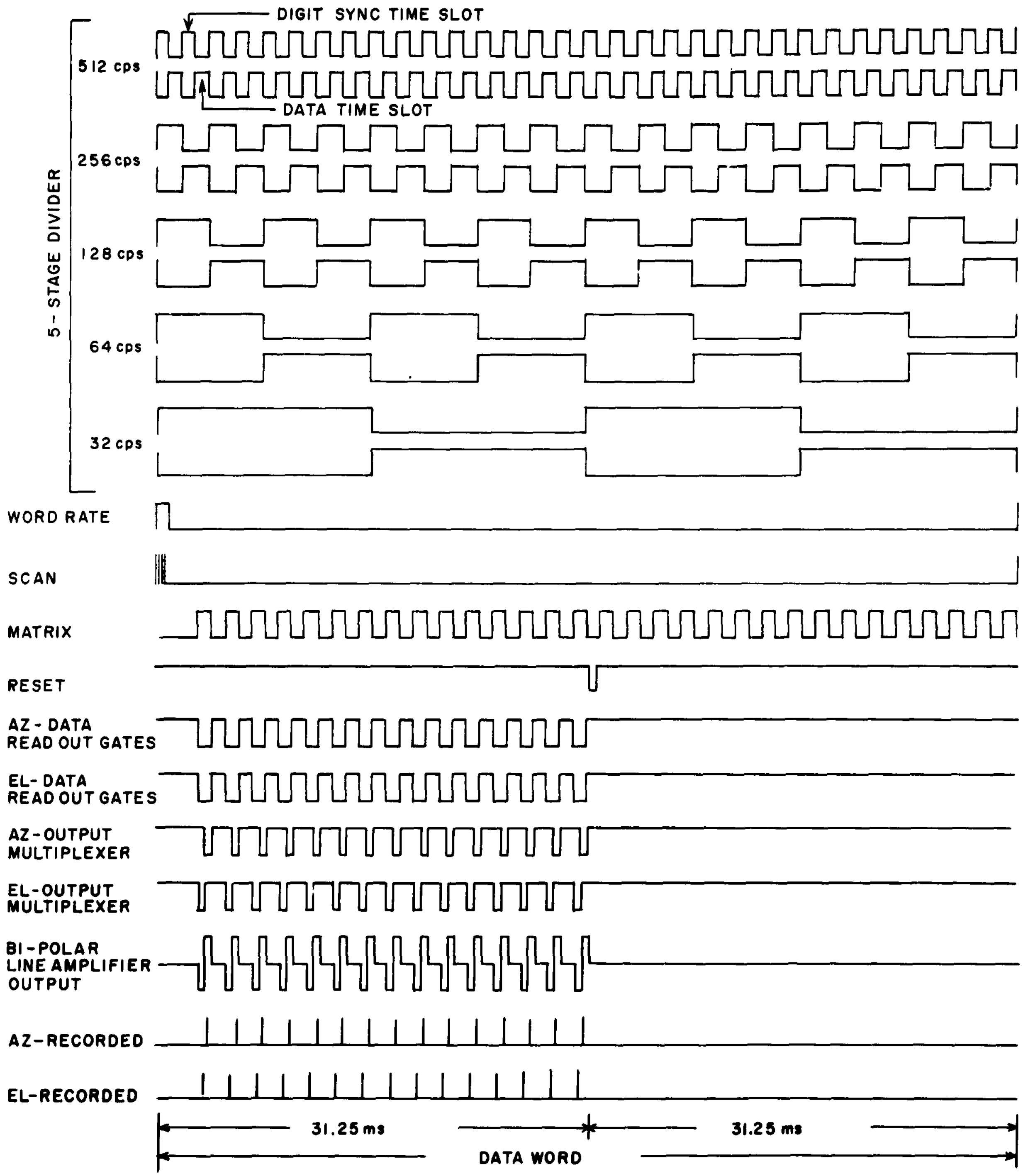


Figure 31. DOTS Data Word Synthesis

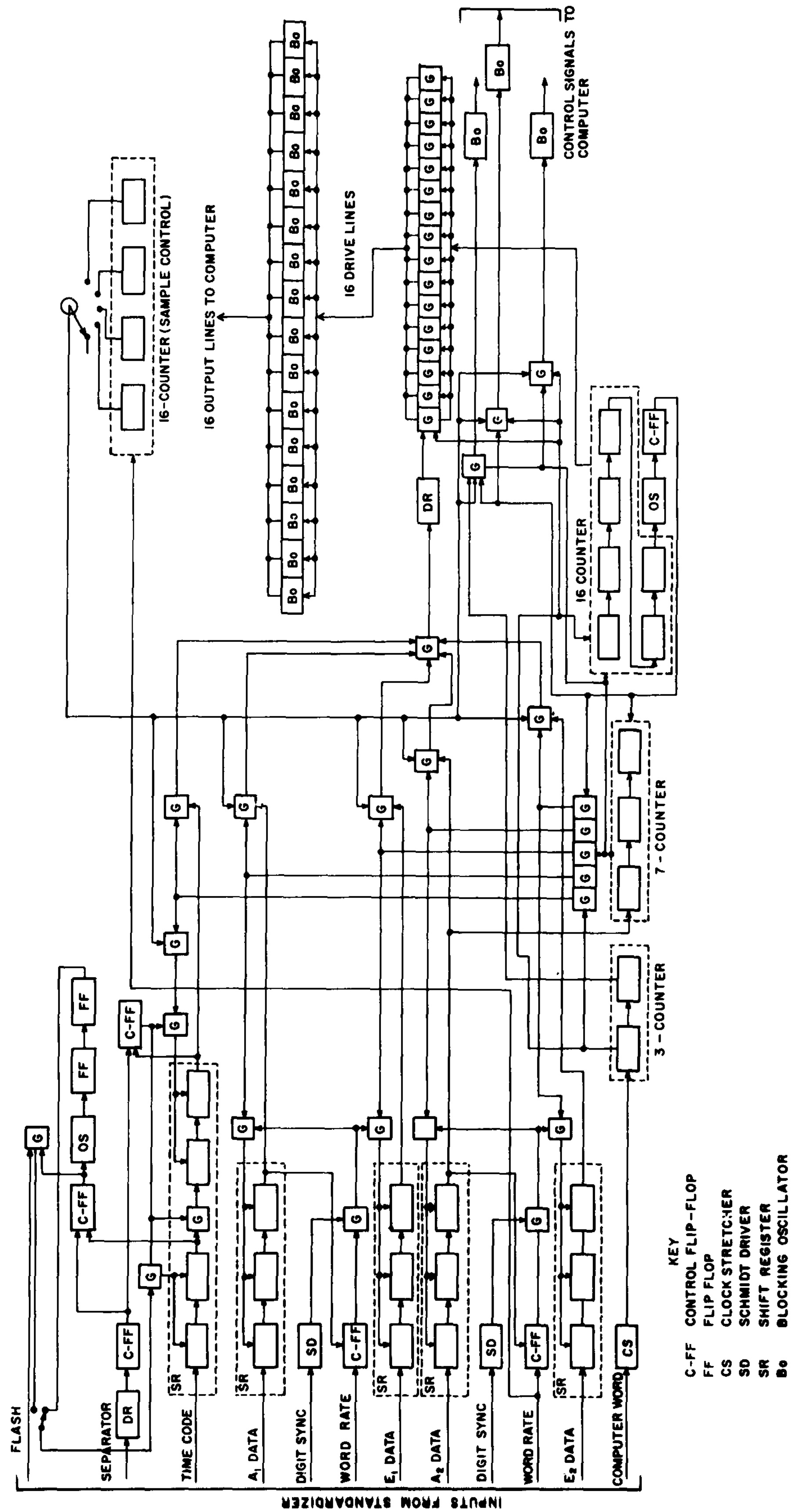


Figure 32. DOTS Converter Block Diagram

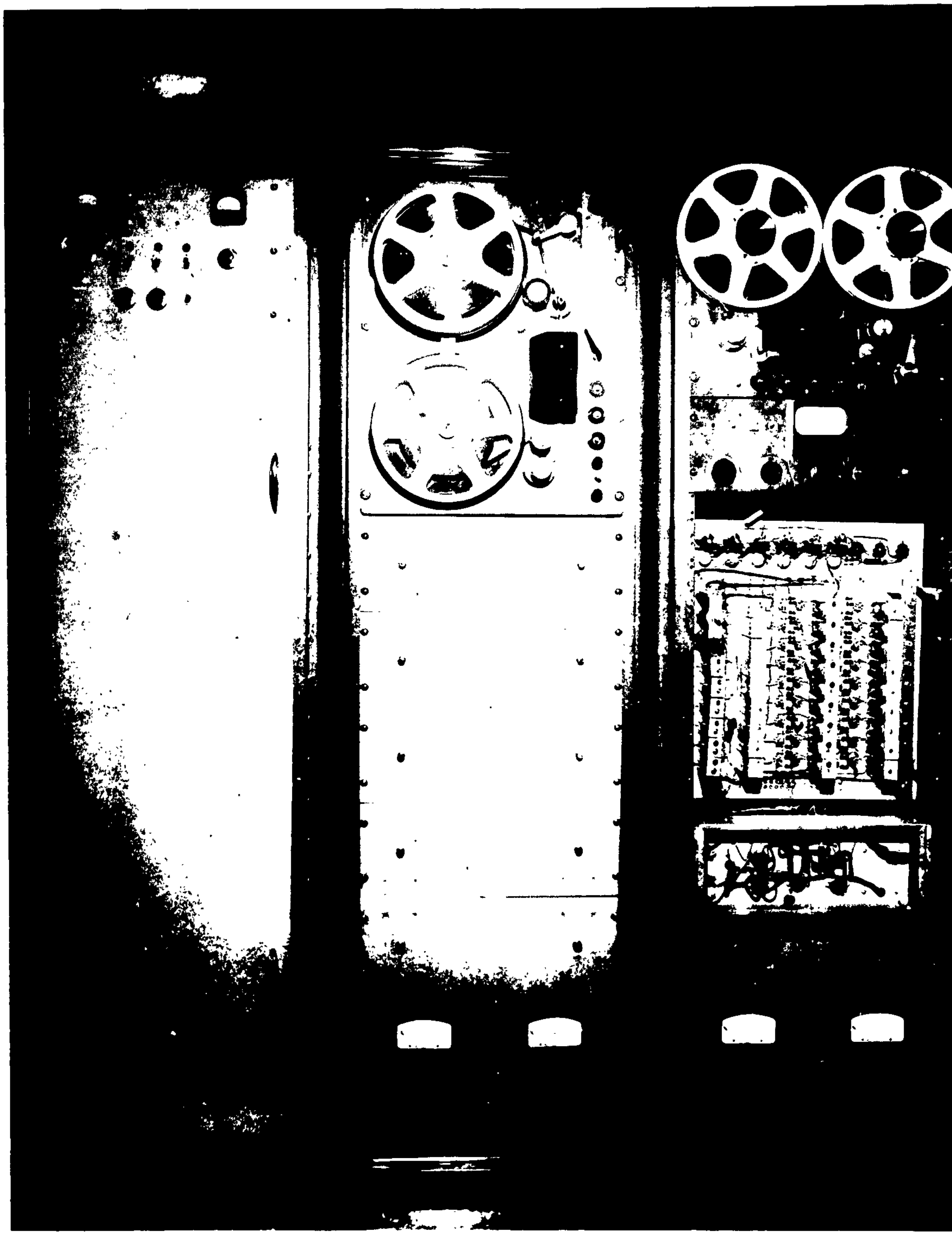


Figure 33. Picture of Playback and Converter Subsystem

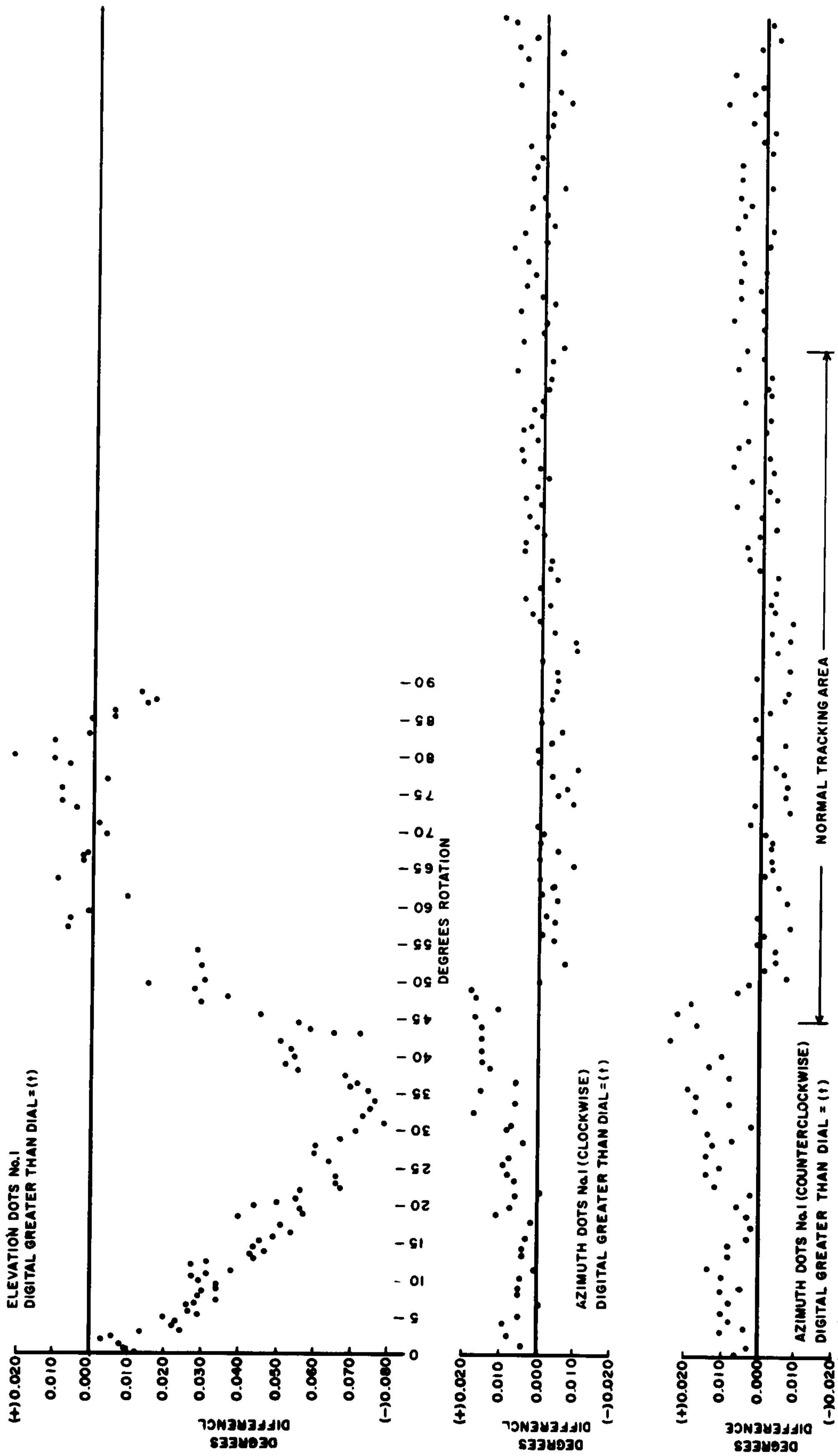


Figure 34. Graph of Differences, Between Dial and Digital Angle Readings

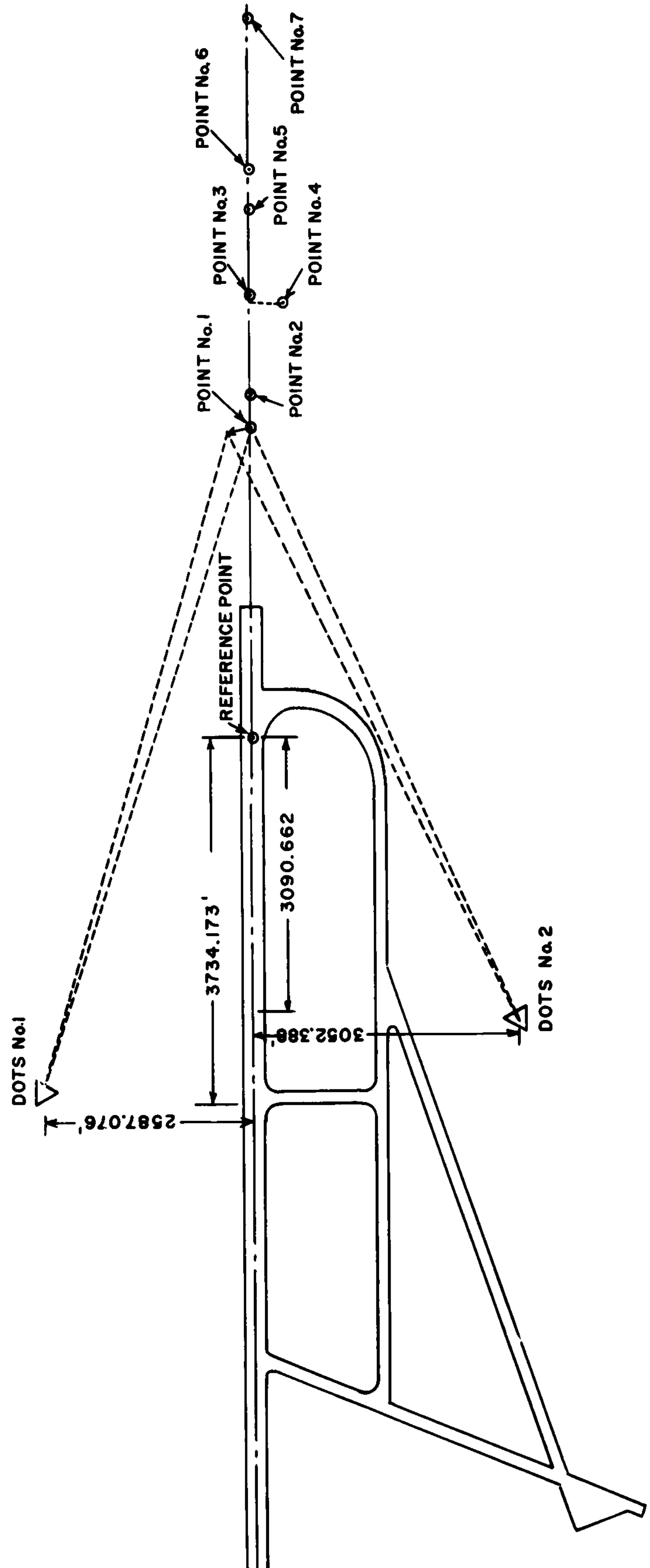


Figure 35. Fixed Target Location Detail

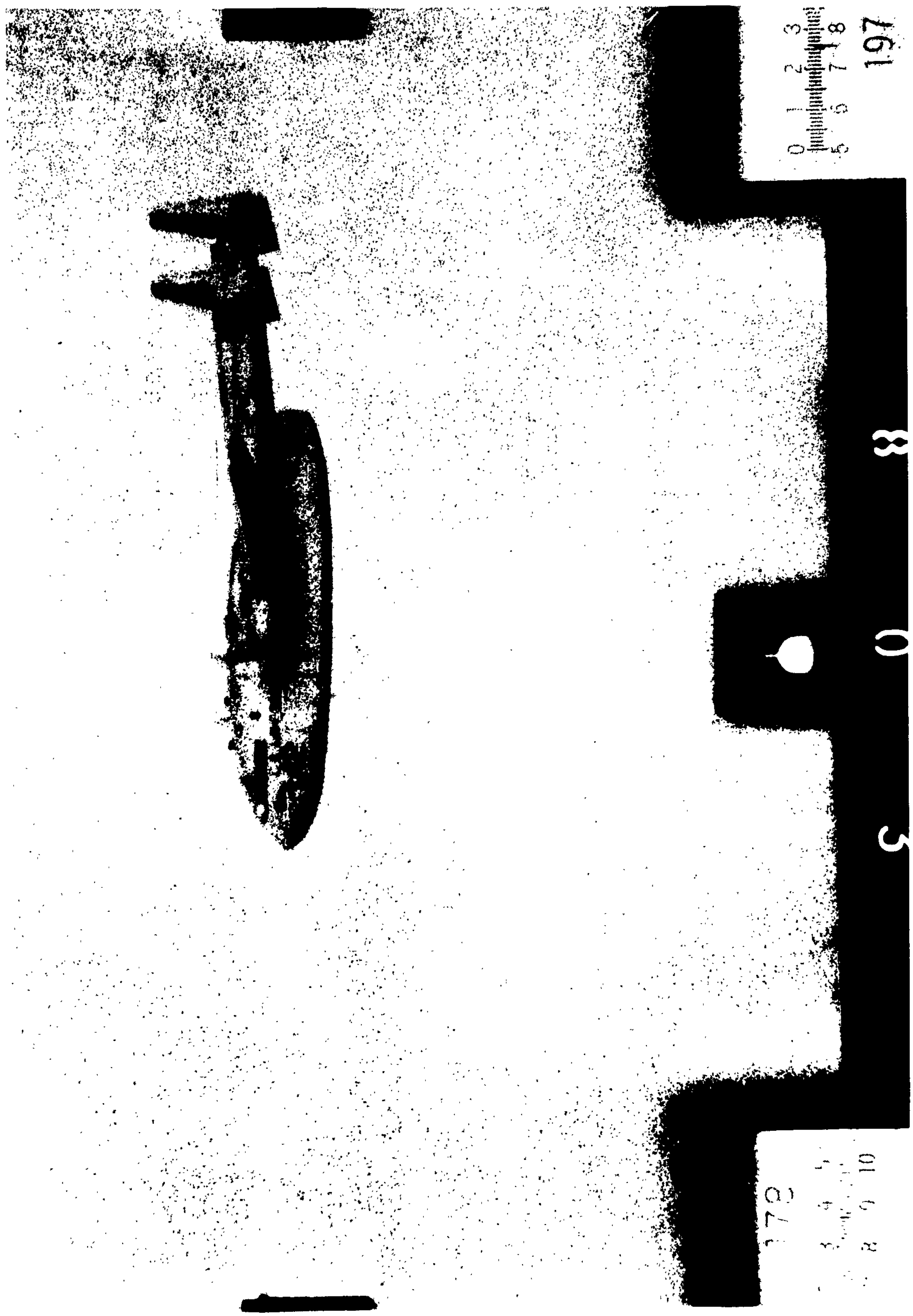


Figure 36. Film Recording Detail

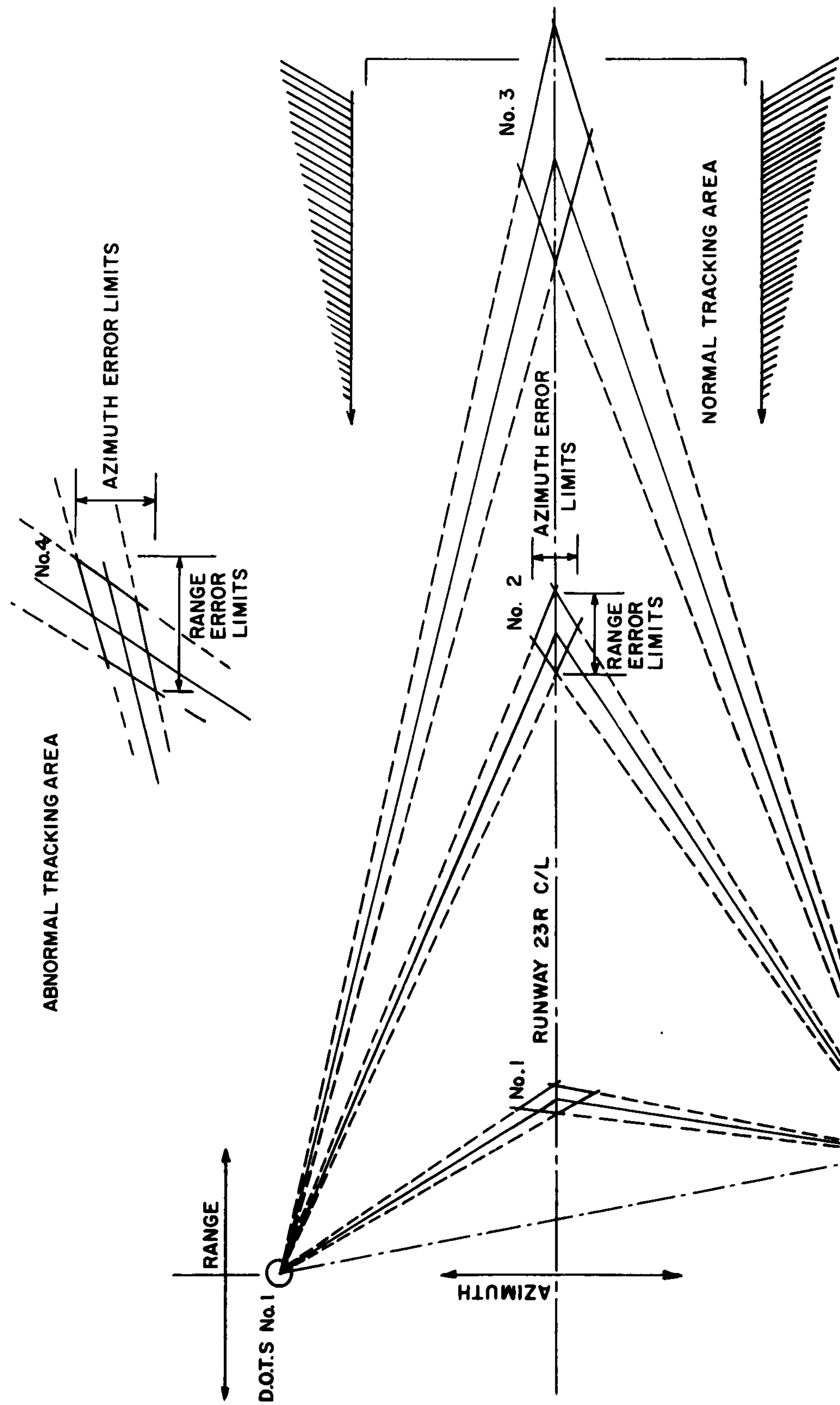


Figure 37. Range and Azimuth Error Quadrilateral

Directorate of Test Data, Deputy for Test and Support, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. DIGITAL OPTICAL TRACKING SYSTEM, by Albert J.F. Smith. Jan 1962. 69 p. incl. illus. & tables. (Proj. 6460; Task 64601)(ASD TR 61-358) Unclassified report.

This space-position measurement system comprises two Askania Kth 53 cinetheodolite instruments with digital encoders mounted externally on their azimuth and elevation axes, readout electronic equipment including multitrack tape recording and playback subsystems, and a conversion subsystem for entering digital data in a

(over)

UNCLASSIFIED

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Burroughs 205 computer.

Digitally, angular position readings are possible to ±1 part in 32768, and by a small modification, can be extended for azimuth angles to ±1 part in 65536. Sampling rates are 1, 2, 4, 8, or 16 per second.

Instrument dial angular position capability is five seconds of arc, for which film recordings are available for visual scanning.

Time, recorded in binary code, is accumulated each 2-second period in groups of eight frames each. Time correlation exists within the system, and is possible with external systems.

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Directorate of Test Data, Deputy for Test and Support, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. DIGITAL OPTICAL TRACKING SYSTEM, by Albert J.F. Smith. Jan 1962. 69 p. incl. illus. & tables. (Proj. 6460; Task 64601)(ASD TR 61-358) Unclassified report.

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(over)

UNCLASSIFIED

UNCLASSIFIED

Burroughs 205 computer.

Digitally, angular position readings are possible to ±1 part in 32768, and by a small modification, can be extended for azimuth angles to ±1 part in 65536. Sampling rates are 1, 2, 4, 8, or 16 per second.

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